

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
30 November 2000 (30.11.2000)

PCT

(10) International Publication Number  
WO 00/71714 A2

(51) International Patent Classification<sup>7</sup>: C12N 15/12,  
C07K 14/755, 14/705, A61K 38/37, 38/17, 31/70, 48/00

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(21) International Application Number: PCT/US00/14111

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(25) Filing Language: English

(81) Designated States (national): AU, CA, JP, US.

(26) Publication Language: English

(84) Designated States (regional): European patent (AT, BE,  
CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC,  
NL, PT, SE).

(30) Priority Data:  
60/135,847 24 May 1999 (24.05.1999) US

Published:

— *Without international search report and to be republished upon receipt of that report.*

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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

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WO 00/71714 A2

(54) Title: METHODS OF REDUCING FACTOR VIII CLEARANCE AND COMPOSITIONS THEREFOR

(57) Abstract: The present invention provides methods of increasing the half-life of factor VIII. More specifically, the invention provides methods of increasing the half-life of factor VIII by substituting amino acids in the A2 domain or in the C2 domain of factor VIII or in both domains. It further provides factor VIII mutants produced by these methods. The invention also provides a method of using receptor-associated protein (RAP) to increase the half-life of factor VIII. The invention also provides polynucleotides encoding the mutant factor VIII, polynucleotides encoding RAP, and methods of treating hemophilia using the polypeptides and polynucleotides of the invention.

## Methods of Reducing Factor VIII Clearance and Compositions Therefor

### *Statement as to Rights to Inventions Made Under Federally-Sponsored Research and Development*

5 Part of the work performed during development of this invention utilized U.S. Government funds. The U.S. Government has certain rights in this invention.

### *Background of the Invention*

#### *Field of the Invention*

10 This invention relates generally to a mutant factor VIII having increased half-life, methods of production, pharmaceutically acceptable compositions and uses thereof. This invention also relates to a method of using receptor associated protein to increase the half-life of factor VIII, methods of production, pharmaceutically acceptable compositions and uses thereof.

#### *Related Art*

15 Coagulation of blood occurs by either the "intrinsic pathway" or the "extrinsic pathway," whereby certain blood proteins interact in a cascade of proteolytic activations to ultimately convert soluble fibrinogen to insoluble fibrin. These threads of fibrin are cross-linked to form the scaffolding of a clot; without 20 fibrin formation, coagulation cannot occur.

25 The intrinsic pathway consists of seven steps: (1) the proteolytic activation of factor XII; (2) activated factor XII cleaves factor XI to activate it; (3) activated factor XI cleaves factor IX, thereby activating it; (4) activated factor IX interacts with activated factor VIII to cleave and activate factor X; (5) activated factor X binds to activated factor V on a membrane surface, which complex proteolytically cleaves prothrombin to form thrombin; (6) thrombin proteolytically cleaves fibrinogen to form fibrin; (7) fibrin monomers assemble into fibrils, which are then cross-linked by factor XIII.

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The extrinsic pathway consists of the following steps: (1) upon rupture of a blood vessel, factor VII binds to tissue factor, a lipoprotein present in tissues outside the vascular system; (2) factor VII is activated to factor VIIa by proteolytic cleavage; and (3) the factor VIIa-tissue factor complex cleaves and activates factor X. Thereafter, the extrinsic pathway is identical to the intrinsic pathway, *i.e.* the two pathways share the last three steps described above.

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The plasma glycoprotein factor VIII circulates as an inactive precursor in blood, bound tightly and non-covalently to von Willebrand factor. Factor VIII (fVIII) is proteolytically activated by thrombin or factor Xa, which dissociates it from von Willebrand factor (vWF) and activates its procoagulant function in the cascade. In its active form, factor VIIIa (fVIIIa) functions as a cofactor for the factor X activation enzyme complex in the intrinsic pathway of blood coagulation, and it is decreased or nonfunctional in patients with hemophilia A.

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In hemophilia, blood coagulation is impaired by a deficiency in certain plasma blood coagulation factors. People with deficiencies in factor VIII or with antibodies against factor VIII suffer uncontrolled internal bleeding that may cause a range of serious symptoms unless they are treated with factor VIII. Symptoms range from inflammatory reactions in joints to early death. The classic definition of factor VIII, in fact, is that substance present in normal blood plasma that corrects the clotting defect in plasma derived from individuals with hemophilia A. A deficiency in vWF can also cause phenotypic hemophilia A because vWF is an essential component of functional factor VIII. In these cases, the half-life of factor VIII is decreased to such an extent that it can no longer perform its particular functions in blood-clotting.

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25 The fVIII protein consists of a homologous A and C domains and a unique B domain which are arranged in the order A1-A2-B-A3-C1-C2 (Vehar, G.A., *et al.*, *Nature* 312:337-340 (1984)). It is processed to a series of  $\text{Me}^{2+}$  linked heterodimers produced by cleavage at the B-A3 junction (Fay, P.J., *et al.*, *Biochem. Biophys. Acta.* 871:268-278 (1986)), generating a light chain (LCh)

consisting of an acidic region (AR) and A3, C1, and C2 domains and a heavy chain (HCh) which consists of the A1, A2, and B domains (Fig. 1).

Activation of fVIII by thrombin leads to dissociation of activated fVIII (fVIIIa) from vWF and at least a 100-fold increase of the cofactor activity. The 5 fVIIIa is a A1/A2/A3-C1-C2 heterotrimer (Fay, P.J., *et al.*, *J. Biol. Chem.* 266:8957-8962 (1991)) in which domains A1 and A3 retain the metal ion linkage (Fig. 1) and the stable dimer A1/A3-C1-C2 is weakly associated with the A2 subunit through electrostatic forces (Fay, P.J., *et al.*, *J. Biol. Chem.* 266:8957-8962 (1991)). Spontaneous dissociation of the A2 subunit from the heterotrimer results 10 in non-proteolytic inactivation of fVIIIa.

Infusion of fVIII/vWF complex or purified plasma or recombinant fVIII into patients with severe hemophilia A who do not have fVIII (Fijnvandraat, K., *et al.*, *Thromb. Haemostas.* 77:298-302 (1997); Morfini, M., *et al.*, *Thromb. Haemostas.* 68:433-435 (1992)) or in normal individuals (Over, J., *et al.*, *J. Clin. Invest.* 62:223-234 (1978)) results in a similar fVIII disappearance with a half-life 15 of 12-14 hours. Although the complex between fVIII and vWF is crucial for normal half-life and level of factor VIII in the circulation, the mechanisms associated with turnover of fVIII/vWF complex are not well defined.

The human factor VIII gene was isolated and expressed in mammalian 20 cells (Toole, J. J., *et al.*, *Nature* 312:342-347 (1984); Gitschier, J., *et al.*, *Nature* 312:326-330 (1984); Wood, W. I., *et al.*, *Nature* 312:330-337 (1984); Vehar, G. A., *et al.*, *Nature* 312:337-342 (1984); WO 87/04187; WO 88/08035; WO 88/03558; U.S. Pat. No. 4,757,006), and the amino acid sequence was deduced 25 from cDNA. Capon *et al.*, U.S. Pat. No. 4,965,199, disclose a recombinant DNA method for producing factor VIII in mammalian host cells and purification of human factor VIII. Human factor VIII expression in CHO (Chinese hamster ovary) cells and BHKC (baby hamster kidney cells) has been reported. Human factor VIII has been modified to delete part or all of the B domain (U.S. Pat. No. 4,868,112), and replacement of the human factor VIII B domain with the human 30 factor V B domain has been attempted (U.S. Pat. No. 5,004,803). The cDNA

sequence encoding human factor VIII and predicted amino acid sequence are shown in SEQ ID NOs:1 and 2, respectively.

U.S. Patent No. 5,859,204, Lollar, J.S., describes mutants of human factor VIII having reduced antigenicity and reduced immunoreactivity.

5 Porcine factor VIII has been isolated and purified from plasma (Fass, D. N., *et al.*, *Blood* 59:594 (1982)). Partial amino acid sequence of porcine factor VIII corresponding to portions of the N-terminal light chain sequence having homology to ceruloplasmin and coagulation factor V and largely incorrectly located were described by Church, *et al.*, *Proc. Natl. Acad. Sci. USA* 81:6934  
10 (1984). Toole, J. J., *et al.*, *Nature* 312:342-347 (1984) described the partial sequencing of the N-terminal end of four amino acid fragments of porcine factor VIII but did not characterize the fragments as to their positions in the factor VIII molecule. The amino acid sequence of the B and part of the A2 domains of porcine factor VIII were reported by Toole, J. J., *et al.*, *Proc. Natl. Acad. Sci. USA*  
15 83:5939-5942 (1986). The cDNA sequence encoding the complete A2 domain of porcine factor VIII and predicted amino acid sequence and hybrid human/porcine factor VIII having substitutions of all domains, all subunits, and specific amino acid sequences were disclosed in U.S. Pat. No. 5,364,771 by Lollar and Runge, and in WO 93/20093. More recently, the nucleotide and  
20 corresponding amino acid sequences of the A1 and A2 domains of porcine factor VIII and a chimeric factor VIII with porcine A1 and/or A2 domains substituted for the corresponding human domains were reported in WO 94/11503. U.S. Patent No. 5,859,204, Lollar, J.S., discloses the porcine cDNA and deduced amino acid sequences.

25 Cellular endocytosis mediated by LRP was shown to be a mechanism of removal of a number of structurally unrelated ligands including several proteins related to coagulation or fibrilolysis. These ligands are: complexes of thrombin with antithrombin III (ATIII), heparin cofactor II (HCII) (Kounnas, M.Z., *et al.*, *J. Biol. Chem.* 271:6523-6529 (1996)), protease nexin I (Knauer, M.F., *et al.*, *J. Biol. Chem.* 272:12261-12264 (1997)), complexes of urokinase-type and tissue-

type plasminogen activators (u-PA and t-PA, respectively) with plasminogen activator inhibitor (PAI-1) (Nykjaer, A., *et al.*, *J. Biol. Chem.* 267:14543-14546 (1992); Orth, K., *et al.*, *Proc. Natl. Acad. Sci.* 89:7422-7426 (1992)), thrombospondin (Mikhailenko, I., *et al.*, *J. Biol. Chem.* 272:6784-6791 (1997)), 5 tissue factor pathway inhibitor (TFPI) (Warshawsky, I., *et al.*, *Proc. Natl. Acad. Sci.* 91:6664-6668 (1994)), and factor Xa (Narita, M., *et al.*, *Blood* 91:555-560 (1998); Ho, G., *et al.*, *J. Biol. Chem.* 271:9497-9502 (1996)).

LRP, a large cell-surface glycoprotein identical to  $\alpha_2$ -macroglobulin receptor (Strickland, D.K., *et al.*, *J. Biol. Chem.* 265:17401-17404 (1990)), is a 10 member of the low density lipoprotein (LDL) receptor family which also includes the LDL receptor, very low density lipoprotein (VLDL) receptor, vitellogenin receptor and glycoprotein 330 receptor. LRP receptor consists of the non-covalently linked 515 kDa  $\alpha$ -chain (Herz, J., *et al.*, *EMBO J.* 7:4119-4127 (1988)) containing binding sites for LRP ligands, and the 85 kDa transmembrane  $\beta$ -chain. 15 Within the  $\alpha$ -chain, cluster of cysteine-rich class A repeats is responsible for ligand binding (Moestrup, S. K., *et al.*, *J. Biol. Chem.* 268:13691-13696 (1993)). In contrast to the acidic ligand binding region in LRP, ligands of LRP expose regions rich in positively charged amino acid residues (Moestrup, S.K., *Biochim. Biophys. Acta* 1197:197-213 (1994)). This type of binding and 31 class A repeats 20 present in LRP may be responsible for its wide ligand diversity and ability to serve as a multi-ligand clearance receptor. LRP is expressed in many cell types and tissues including placenta, lung and brain (Moestrup, S.K., *et al.*, *Cell Tissue Res.* 269:375-382 (1992)) and is a major endocytic receptor in the liver (Strickland, D.K., *et al.*, *FASEB J.* 9:890-898 (1995)).

25 A 39 kDa receptor-associated protein (RAP) binds to LRP with high affinity ( $K_d$ =4 nM (27)) and inhibits binding and LRP-mediated internalization and degradation of all ligands (Moestrup, S.K., *Biochim. Biophys. Acta* 1197:197-213 (1994); Williams, S.E., *et al.*, *J. Biol. Chem.* 267:9035-9040 (1992)), therefore serving as a useful tool for testing whether LRP is involved in 30 endocytosis of a given ligand.

Severe hemophiliacs, who number about 10,000 in the United States, can be treated with infusion of human factor VIII, vWF/factor VIII complex or vWF which will restore the blood's normal clotting ability if administered with sufficient frequency and concentration. However, supplies have been inadequate and problems in therapeutic use occur due to difficulty in isolation and purification, immunogenicity, and the necessity of removing the AIDS and hepatitis infectivity risk.

Several preparations of human plasma-derived factor VIII of varying degrees of purity are available commercially for the treatment of hemophilia A. These include a partially-purified factor VIII derived from the pooled blood of many donors that is heat- and detergent-treated for viruses but contains a significant level of antigenic proteins; a monoclonal antibody-purified factor VIII that has lower levels of antigenic impurities and viral contamination; and recombinant human factor VIII, clinical trials for which are underway. Unfortunately, human factor VIII is unstable at physiologic concentrations and pH, is present in blood at an extremely low concentration (0.2 µg/ml plasma), and has low specific clotting activity.

The problems associated with the commonly used, commercially available, plasma-derived factor VIII have stimulated significant interest in the development of a better factor VIII product. There is a need for a more potent factor VIII; a factor VIII that is stable at a selected pH and physiologic concentration; a factor VIII that has a longer half-life in circulating blood.

### *Summary of the Invention*

The present invention relates to a method of increasing the half-life of factor VIII. More specifically, the present invention relates to a mutant of factor VIII having reduced clearance from plasma.

In one embodiment, the mutant factor VIII has one or more amino acid substitutions in the A2 domain.

In a preferred embodiment, the substituted amino acid(s) are important for receptor-dependent clearance of factor VIII, such that the resulting mutant factor VIII has a longer (increased) circulating half-life.

5 In another embodiment, the mutant factor VIII has one or more amino acid substitutions in the C2 domain.

In a preferred embodiment, the substituted amino acid(s) are important for receptor-independent clearance of factor VIII, such that the resulting mutant factor VIII has a longer (increased) circulating half-life.

10 In yet another preferred embodiment, amino acid(s) important for receptor-dependent clearance in the A2 domain and amino acid(s) important for receptor-independent clearance in the C2 domain are substituted, such that the resulting mutant factor VIII has an increased circulating half-life.

15 The invention also relates to a method of using receptor associated protein (RAP) to increase the half-life of factor VIII. Further aspects of the invention include a method of producing factor VIII mutants having an increased half-life, pharmaceutically acceptable compositions thereof, and a method of treating factor VIII deficiency using mutant factor VIII of the invention and/or RAP.

### *Brief Description of the Figures*

20 FIG. 1. Domain structure of fVIII and its fragments. The domain structure of mature fVIII protein is shown in line 1. The LCh acidic region is labeled as AR. Thrombin-cleaved LCh (A3-Cl-C2), heterotrimeric fVIIIA (A1/A2/3-Cl-C2) and heterodimer A1/A3-Cl-C2 are shown in lines 2, 3 and 4.

25 FIGs. 2A and 2B. The amino acid sequence of mature, B-domainless fVIII (SEQ ID NO:5; composed from GenBank Accession No. X01179). The A2 sequence within fVIII is underlined and the sequence of the LRP binding site (residues 484-509) within A2 is indicated with asterisks. The amino acid residues shown as one-letter amino acid abbreviations.

FIGS. 3A and 3B. The deduced amino acid sequence of full-length factor VIII (SEQ ID NO:2; from GenPep Accession No. CAA25619.1 and GenBank Accession No. X01179).

5 FIG. 4. The deduced amino acid sequence of RAP (SEQ ID NO:4; GenBank Accession No. M63959). The signal sequence (amino acids 1-34) is underlined and the LDL receptor binding region (amino acids 237-353) is indicated with asterisks.

10 FIGS. 5A and 5B. Binding of  $^{125}\text{I}$ -fVIII to purified LRP by ligand competition assay.  $^{125}\text{I}$ -fVIII (1 nM) was incubated for 1 h at 37°C in wells coated with LRP (●) or BSA (○) in the presence of increasing concentrations of unlabeled competitors, fVIII (●, ○) or vWF (Δ), *panel A*, and RAP (●, ○), *panel B*. In the experiment (Δ),  $^{125}\text{I}$ -fVIII was preincubated with vWF for 30 min at 37°C, prior to its addition to the wells. Following incubation, the wells were washed and  $^{125}\text{I}$ -fVIII binding was determined. Binding of  $^{125}\text{I}$ -fVIII in the presence of unlabeled fVIII, vWF, or RAP is expressed as the percentage of  $^{125}\text{I}$ -fVIII binding, when no competitor was added. Each point represents the mean value of triplicates and the error bars display the standard deviation. The curves show a best fit of the data to a model describing heterologous ligand displacement from a single class of binding sites using the program LIGAND.

15 20 FIG. 6. Effect of fragments of fVIII on its binding to LRP.  $^{125}\text{I}$ -fVIII (1 nM) and increasing concentrations of unlabeled HCh (●), A2 (▲), LCh (○) or A1/A3-Cl-C2 (Δ) were incubated with LRP as described in Fig. 5. Each point represents the mean value and the standard deviation of the triplicates. The data were fitted as in Fig. 5 to a model describing heterologous ligand displacement from a single 25 class of binding sites with  $K_i$  values of 120 and 132 nM for HCh and A2, respectively.

30 FIGS. 7A and 7B. Effect of monoclonal antibodies and synthetic peptides on  $^{125}\text{I}$ -fVIII binding to purified LRP. *Panel A*,  $^{125}\text{I}$ -fVIII (1 nM) and increasing concentrations of mAbs 413 (●) or T5 (○) were added to LRP coated wells as described in Fig. 5. In the control experiment (Δ),  $^{125}\text{I}$ -fVIII and increasing

concentrations of mAb 413 were added to BSA coated wells. *Panel B*,  $^{125}\text{I}$ -fVIII and increasing concentrations of synthetic peptides consisting of the A2 domain residues 484-509 (●) or 432-456 (○) were added to LRP coated wells. In the control experiment (Δ),  $^{125}\text{I}$ -fVIII and increasing concentrations of the peptide 484-509 were added to BSA coated wells. In the panels A and B, binding of  $^{125}\text{I}$ -fVIII in the presence antibodies or peptides is expressed as the percentage of its binding, when no competitor was added. The mean and standard deviation of the triplicate measurements are presented.

FIGS. 8A and 8B. Internalization and degradation of  $^{125}\text{I}$ -fVIII/vWF complex by LRP-expressing (MEF) and LRP-deficient (PEA 13) fibroblasts. Wells containing  $2 \times 10^4$  of each MEF (○, ●) or PEA 13 cells (Δ, ▲) were incubated with 1 nM  $^{125}\text{I}$ -fVIII/vWF in the absence (closed symbols) or presence (opened symbols) of RAP (1  $\mu\text{M}$ ).  $^{125}\text{I}$ -fVIII/vWF complex was prepared by incubation of  $^{125}\text{I}$ -fVIII with unlabeled vWF at a molar ratio 1:50 for 30 min at 37°C. At the indicated times, the amounts of internalized  $^{125}\text{I}$ -fVIII (*panel A*) and degraded  $^{125}\text{I}$ -fVIII (*panel B*) by the MEF and PEA 13 fibroblasts were determined as described under Experimental Procedures. In the experiment (▽), degradation of  $^{125}\text{I}$ -fVIII (1 nM) by MEF cells in the presence of (0.1 mM) chloroquine is shown. Each data point represents the mean and standard deviation of duplicate determinations.

FIGS. 9A and 9B. Comparison of internalization of isolated  $^{125}\text{I}$ -fVIII and components of fVIII/vWF complex. Wells containing  $2 \times 10^5$  of each MEF and PEA 13 cells were incubated with 1 nM of isolated  $^{125}\text{I}$ -fVIII or 1 nM of fVIII/vWF complex formed by mixing either  $^{125}\text{I}$ -fVIII (1 nM) with unlabeled vWF (50 nM) or  $^{125}\text{I}$ -vWF (50 nM) with unlabeled fVIII (1 nM). Following incubation for 6 hours with MEF cells in the absence of RAP (open bars) or in the presence of 1  $\mu\text{M}$  RAP (solid bars) or after incubation with PEA 13 cells (hatched bars) the amounts of internalized (*panel A*) and degraded (*panel B*) isolated  $^{125}\text{I}$ -fVIII, and  $^{125}\text{I}$ -fVIII or  $^{125}\text{I}$ -vWF from the fVIII/vWF complex were determined as described

in Fig. 8. The data shown are an average of duplicate determinations  $\pm$  standard deviation.

FIGS. 10A and 10B. The A2 domain of fVIII inhibits the internalization and degradation of  $^{125}\text{I}$ -fVIII/vWf complex by MEF fibroblasts. One nM of  $^{125}\text{I}$ -fVIII/vWf complex was prepared as in Fig. 8 and incubated with  $2 \times 10^5$  of MEF cells in presence of 1  $\mu\text{M}$  of A2 (○), 1  $\mu\text{M}$  of A1/A3-Cl-C2 (Δ), or in the absence of any competitor (●). At the indicated times, the amounts of internalized (*panel A*) and degraded  $^{125}\text{I}$ -fVIII (*panel B*) were determined as in Fig. 8. Each data point represents the mean and standard deviation of duplicate determinations.

FIGS. 11A-D. Internalization and degradation of  $^{125}\text{I}$ -A2 by MEF fibroblasts and by LRP-expressing smooth muscle cells (SMC) and alveolar epithelial cells (T2). In the *panels A and B*,  $2 \times 10^5$  of MEF (○, ●) or PEA 13 cells (Δ, ▲) were incubated with 10 nM  $^{125}\text{I}$ -A2 in the absence (closed symbols) or presence (opened symbols) of RAP (1  $\mu\text{M}$ ). At the indicated times, the amounts of internalized  $^{125}\text{I}$ -A2 (*panel A*) and degraded  $^{125}\text{I}$ -A2 (*panel B*) by the MEF and PEA 13 fibroblasts were determined as described in Fig. 8. In the experiment (▽), degradation of  $^{125}\text{I}$ -A2 by MEF cells in the presence (0.1 mM) chloroquine is shown. Each data point represents the mean and standard deviation of duplicate determinations. In the *panels C and D*,  $^{125}\text{I}$ -A2 (10 nM) was incubated for 4 h at 37°C in the wells containing  $3 \times 10^5$  SMC (solid bars) or T2 (open bars) cells in the presence or absence of RAP (1 mM). The amount of  $^{125}\text{I}$ -A2 internalized (*panel C*) and degraded (*panel D*) by the cells was determined as in Fig. 8. The data shown are an average of duplicate determinations  $\pm$  standard deviation.

FIGS. 12A and 12B. The effect of RAP on clearance of  $^{125}\text{I}$ -A2 (A) or  $^{125}\text{I}$ -fVIII/vWf (B) from plasma of mice. BALB/c mice were injected into the tail vein by sample containing  $^{125}\text{I}$ -A2 (36 nM), *panel A*, or  $^{125}\text{I}$ -fVIII/vWf (20 nM), *panel B*, in the absence (●) or presence (○) of RAP (267  $\mu\text{M}$ ). At indicated time points, blood (50  $\mu\text{l}$ ) was collected into 10  $\mu\text{l}$  of 100 mM EDTA and an aliquot (50  $\mu\text{l}$ ) was counted for radioactivity. The percentage of ligand remaining in circulation was calculated considering radioactivity of the aliquot taken at 1 min

after injection as 100%. The clearance of each preparation was examined in two mice, and the data plotted represent the average value  $\pm$  standard deviation.

### *Detailed Description of the Preferred Embodiments*

"Factor VIII" (or "coagulation factor VIII"), as used herein, refers to a plasma glycoprotein that is a member of the intrinsic coagulation pathway and is essential to blood coagulation. A congenital X-linked deficiency of biologically active factor VIII results in Hemophilia A, a potentially life-threatening disorder. Unless otherwise specified or indicated, as used herein, "factor VIII" denotes any functional human factor VIII protein molecule in its normal role in coagulation, including any fragment, analog derivative or modified factor VIII. The human factor VIII cDNA nucleotide and full-length predicted amino acid sequences are shown in SEQ ID NOs:1 and 2, respectively. Human factor VIII peptides of the invention include full-length factor VIII, full-length factor VIII minus Met at the N-terminus, mature factor VIII (minus the signal sequence), mature factor VIII with an additional Met at the N-terminus, and/or factor VIII with or without a B domain. Factor VIII of the invention may also include porcine factor VIII. The cDNA and predicted amino acid sequences of the porcine factor VIII are disclosed in U.S. Patent No.,859,204.

"Subunits" of factor VIII, as used herein, are the heavy and light chains of the protein. The heavy chain of factor VIII contains three domains, A1, A2, and B. The light chain of factor VIII also contains three domains, A3, C1, and C2. Factor VIII is synthesized as an approximately 300 kDa single chain protein with internal sequence homology that defines the "domain" sequence NH<sub>2</sub>-A1-A2-B-A3-C1-C2-COOH.

In a factor VIII molecule, a "domain", as used herein, is a continuous sequence of amino acids that is defined by internal amino acid sequence identity and sites of proteolytic cleavage by thrombin. Unless otherwise specified, factor VIII domains include the following amino acid residues: A1, residues

5                   Ala1-Arg372; A2, residues Ser373-Arg740; B, residues Ser741-Arg1648; A3, residues Ser1690-Ile2032; C1, residues Arg2033-Asn2172; C2, residues Ser2173-Tyr2332. The A3-C1-C2 sequence includes residues Ser1690-Tyr2332. The remaining sequence, residues Glu1649-Arg1689, is usually referred to as the factor VIII light chain activation peptide.

10                  A "B-domainless" factor VIII or "B (-)" factor VIII, or fragment of thereof, as used herein, refers to any one of the factor VIII mutants described herein that lacks the B domain. The amino acid sequence of mature, B (-) factor VIII as constructed from GenBank Accession No. X01179 is shown in Figure 2 (SEQ ID NO:5). B (-) factor VIII of the invention includes B (-) factor VIII with or without a signal sequence and with or without a Met at the N-terminus.

15                  As used herein, a "mutant factor VIII or fragment thereof" or "factor VIII mutant or fragment thereof" is an active factor VIII molecule or fragment thereof comprising at least one amino acid substitution.

20                  "RAP," as used herein, refers to the receptor-associated protein, also called the  $\alpha_2$  macroglobulin receptor-associated protein. RAP reduces receptor-dependent clearance of factor VIII. The human RAP deduced amino acid sequence is shown in Figure 4 (SEQ ID NO:4; GenBank Accession No. P30533). The RAP cDNA sequence is shown in SEQ ID NO:3 and GenBank Accession No. M63959. Mutant RAP proteins of the invention may have an amino acid substitution at one, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, fourteen, fifteen, sixteen, seventeen, eighteen, nineteen, twenty or more positions of RAP. An amino acid substitution at "position" 327, for example, of RAP, refers to an amino acid substitution at amino acid 327 of the RAP amino acid sequence in GenBank Accession No. P30533.

25                  By "amino acid substitution" is meant a substitution of one amino acid for one of the remaining 19 naturally occurring amino acids. By an amino acid substitution at any one of positions "484 to 509," for example, is meant an amino acid substitution any position in the range, including at positions 484 and 509. The mutant factor VIII or RAP proteins of the invention may have an amino acid

substitution at one, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, fourteen, fifteen, sixteen, seventeen, eighteen, nineteen, twenty or more positions.

5 An amino acid substitution at "position" 499, for example, of factor VIII, refers to an amino acid substitution at position 499 according to the numbering system of Wood *et al.*, *Nature* 312:330-337 (1984).

10 "Half-life," as used herein, refers to the half-life of factor VIII in circulation, as determined in animals such as mice, for example, using the method of Examples 1 and 2. Factor VIII has a half-life of 12-14 hours. As provided herein, methods to increase the half-life of factor VIII would lead to a factor VIII half-life of longer than 12-14 hours.

15 "Receptor-dependant clearance," as used herein, refers to the receptor-mediated removal of factor VIII from circulation. As described in the examples, receptor-dependant clearance is exhibited by MEF cells, and is inhibited by RAP. Receptor-dependent clearance includes, but is not limited, to LRP-mediated clearance of factor VIII clearance. Additional receptors may be involved in receptor-dependent clearance.

20 "Receptor-independent clearance," as used herein, refers to the removal of factor VIII from circulation by means different from receptor-dependant clearance. RAP does not inhibit receptor-independent clearance.

25 "Factor VIII deficiency," as used herein, includes deficiency in clotting activity caused by production of defective factor VIII, by inadequate or no production of factor VIII, or by partial or total inhibition of factor VIII by inhibitors. Hemophilia A is a type of factor VIII deficiency resulting from a defect in an X-linked gene and the absence or deficiency of the factor VIII protein it encodes. A deficiency in vWF can also cause phenotypic hemophilia A because vWF is an essential component of functional factor VIII. In these cases, the half-life of factor VIII is decreased to such an extent that it can no longer perform its particular functions in blood-clotting.

"Plasma," as used herein, refers to the fluid, non-cellular portion of the blood of humans or animals as found prior to coagulation. It is distinguished from serum, which is obtained after coagulation.

5 "Pharmaceutically acceptable carrier," as used herein, refers to a non-toxic solid, semisolid or liquid filler, diluent, encapsulating material or formulation auxiliary of any type.

"Patient," as used herein, refers to human or animal individuals receiving medical care and/or treatment.

10 "Congenital deficiency," as used herein, refers to the condition of an individual that lacks, as a result of heredity, a compound found in normal individuals. Congenital deficiencies are permanent absent transplantation or genetic intervention, which at this time are not guaranteed cures.

15 "Acquired deficiency," as used herein, refers to the condition of an individual that lacks, as a result of a non-congenital influence, a compound found in normal individuals. Acquired deficiencies are frequently the transient result of other conditions or their treatment, but are nonetheless debilitating and life threatening.

20 A "fusion protein," as used herein, is the product of a gene in which the coding sequence for one protein is extensively altered, for example, by fusing part of it to the coding sequence for a second protein from a different gene to produce a gene that encodes the fusion protein. As used herein, a fusion protein is a subset of the factor VIII protein or RAP protein described in this application.

25 A "corresponding" nucleic acid or amino acid or corresponding sequence of either, as used herein, is one present at a site in a factor VIII or mutant factor VIII molecule or fragment thereof that has the same structure and/or function as a site in the factor VIII molecule of another species, although the nucleic acid or amino acid number may not be identical.

"Procoagulant activity," as used herein, refers to factor VIII coagulation activity exhibited in a human factor VIII assay.

5                   "Specific activity," as used herein, refers to the activity that will correct the coagulation defect of human factor VIII deficient plasma. Specific activity is measured in units of clotting activity per milligram total factor VIII protein in a standard assay in which the clotting time of human factor VIII deficient plasma is compared to that of normal human plasma. One unit of factor VIII activity is the activity present in one milliliter of normal human plasma. In the assay, the shorter the time for clot formation, the greater the activity of the factor VIII being assayed. Mutant factor VIII has coagulation activity in a human factor VIII assay. This activity may be less than, equal to, or greater than that of either 10 plasma-derived or recombinant human factor VIII.

15                  "Polypeptides," "molecules" and "proteins," as used herein, includes all polypeptides as described below. The basic structure of polypeptides is well known and has been described in innumerable textbooks and other publications in the art. In this context, the term is used herein to refer to any peptide or protein comprising two or more amino acids joined to each other in a linear chain by peptide bonds. As used herein, the term refers to both short chains, which also commonly are referred to in the art as peptides, oligopeptides and oligomers, for example, and to longer chains, which generally are referred to in the art as proteins, of which there are many types.

20                  It will be appreciated that polypeptides often contain amino acids other than the 20 amino acids commonly referred to as the 20 naturally occurring amino acids, and that many amino acids, including the terminal amino acids, may be modified in a given polypeptide, either by natural processes, such as processing and other post-translational modifications, but also by chemical modification 25 techniques which are well known to the art. Even the common modifications that occur naturally in polypeptides are too numerous to list exhaustively here, but they are well described in basic texts and in more detailed monographs, as well as in a voluminous research literature, and they are well known to those of skill in the art. Among the known modifications which may be present in polypeptides 30 of the present invention are, to name an illustrative few, acetylation, acylation,

ADP-ribosylation, amidation, PEGylation, covalent attachment of flavin, covalent attachment of a heme moiety, covalent attachment of a nucleotide or nucleotide derivative, covalent attachment of a lipid or lipid derivative, covalent attachment of phosphotidylinositol, cross-linking, cyclization, disulfide bond formation, 5 demethylation, formation of covalent cross-links, formation of cystine, formation of pyroglutamate, formulation, gamma-carboxylation, glycosylation, GPI anchor formation, hydroxylation, iodination, methylation, myristylation, oxidation, proteolytic processing, phosphorylation, prenylation, racemization, selenoylation, sulfation, transfer-RNA mediated addition of amino acids to proteins such as 10 arginylation, and ubiquitination.

Such modifications are well known to those of skill and have been described in great detail in the scientific literature. Several particularly common modifications, glycosylation, lipid attachment, sulfation, gamma-carboxylation of glutamic acid residues, hydroxylation and ADP-ribosylation, for instance, are 15 described in most basic texts, such as, for instance *Proteins – Structure and Molecular Properties*, 2nd Ed., T. E. Creighton, W.H. Freeman and Company, New York (1993). Many detailed reviews are available on this subject, such as, for example, those provided by Wold, F., *Posttranslational Protein Modifications: Perspectives and Prospects*, pp. 1-12 in *Posttranslational Covalent Modification of Proteins*, B. C. Johnson, Ed., Academic Press, New York (1983); Seifter *et al.*, 20 Analysis for protein modifications and nonprotein cofactors, *Meth. Enzymol.* 182: 626-646 (1990) and Rattan *et al.*, *Protein Synthesis: Post translational Modifications and Aging*, Ann. N.Y. Acad. Sci. 663: 48-62 (1992).

In general, as used herein, the term polypeptide encompasses all such 25 modifications, particularly those that are present in polypeptides synthesized by expressing a polynucleotide in a host cell.

The invention also relates to fragments, "derivatives" and analogs of these 30 polypeptides. The terms "fragment," "derivative" and "analog" when referring to the polypeptides of FIGS. 2, 3 or 4, means a polypeptide which retains essentially the same biological function or activity as such polypeptide. A mutant, fragment

derivative or analog of factor VIII refers to a polypeptide that retains factor VIII procoagulant activity. A mutant, fragment derivative or analog of RAP refers to a polypeptide that retains the ability to reduce receptor-dependent clearance of factor VIII. Thus, an analog includes a proprotein which can be activated by 5 cleavage of the proprotein portion to produce an active mature polypeptide. Fragments, derivatives and analogs are described in detail herein.

A fragment, derivative or analog of the polypeptide of the invention may be (i) one in which one or more of the amino acid residues includes a substituent group, or (ii) one in which the mature polypeptide is fused with another 10 compound, such as a compound to increase the half-life of the polypeptide (for example, polyethylene glycol), or (iii) one in which the additional amino acids are fused to the mature polypeptide, such as a leader or secretory sequence or a sequence which is employed for purification of the mature polypeptide or a proprotein sequence. Such fragments, derivatives and analogs are deemed to be 15 within the scope of those skilled in the art from the teachings herein.

The polypeptide of the present invention may be a recombinant polypeptide, a natural polypeptide or a synthetic polypeptide. In certain preferred embodiments it is a recombinant polypeptide.

Further particularly preferred in this regard are mutants, analogs and 20 fragments; and mutants and analogs of the fragments, having the defined activity and/or having the amino acid sequence of the polypeptides of FIGS. 2, 3 or 4.

The polypeptides and polynucleotides of the present invention are preferably provided in an isolated form, and preferably are purified to homogeneity.

"Polynucleotide(s)" generally refers to any polyribonucleotide or 25 polydeoxyribonucleotide, which may be unmodified RNA or DNA or modified RNA or DNA. Thus, for instance, polynucleotides as used herein refers to, among others, single-and double-stranded DNA, DNA that is a mixture of single-and double-stranded regions, single- and double-stranded RNA, and RNA that is 30 mixture of single- and double-stranded regions, hybrid molecules comprising

DNA and RNA that may be single-stranded or, more typically, double-stranded or a mixture of single- and double-stranded regions. In addition, polynucleotide as used herein refers to triple-stranded regions comprising RNA or DNA or both RNA and DNA. The strands in such regions may be from the same molecule or 5 from different molecules. The regions may include all of one or more of the molecules, but more typically involve only a region of some of the molecules. One of the molecules of a triple-helical region often is an oligonucleotide.

As used herein, the term polynucleotide includes DNAs or RNAs as described above that contain one or more modified bases. Thus, DNAs or RNAs 10 with backbones modified for stability or for other reasons are "polynucleotides" as that term is intended herein. Moreover, DNAs or RNAs comprising unusual bases, such as inosine, or modified bases, such as tritylated bases, to name just two examples, are polynucleotides as the term is used herein.

It will be appreciated that a great variety of modifications have been made 15 to DNA and RNA that serve many useful purposes known to those of skill in the art. The term polynucleotide as it is employed herein embraces such chemically, enzymatically or metabolically modified forms of polynucleotides, as well as the chemical forms of DNA and RNA characteristic of viruses and cells, including simple and complex cells, *inter alia*.

20 Polynucleotides of the present invention may be in the form of RNA, such as mRNA, or in the form of DNA, including, for instance, cDNA and genomic DNA obtained by cloning or produced by chemical synthetic techniques or by a combination thereof. The DNA may be double-stranded or single-stranded. Single-stranded DNA may be the coding strand, also known as the sense strand, 25 or it may be the non-coding strand, also referred to as the anti-sense strand.

Polynucleotides of the present invention may include, but are not limited 30 to the coding sequence for the mature polypeptide, by itself; the coding sequence for the mature polypeptide and additional coding sequences, such as those encoding a leader or secretory sequence, such as a pre-, or pro- or prepro- protein sequence; the coding sequence of the mature polypeptide, with or without the

aforementioned additional coding sequences, together with additional, non-coding sequences, including for example, but not limited to introns and non-coding 5' and 3' sequences, such as the transcribed, non-translated sequences that play a role in transcription, mRNA processing--including splicing and polyadenylation signals, for example--ribosome binding and stability of mRNA; additional coding sequence which codes for additional amino acids, such as those which provide additional functionalities. Thus, for instance, the polypeptide may be fused to a marker sequence, such as a peptide, which facilitates purification of the fused polypeptide. In certain preferred embodiments of this aspect of the invention, the marker sequence is a hexahistidine peptide, such as the tag provided in a pQE vector (Qiagen, Inc.), among others, many of which are commercially available. As described in Gentz *et al.*, *Proc. Natl. Acad. Sci., USA* 86: 821-824 (1989), for instance, hexa-histidine provides for convenient purification of the fusion protein. The HA tag corresponds to an epitope derived of influenza hemagglutinin protein, which has been described by Wilson *et al.*, *Cell* 37: 767 (1984), for instance.

An "effective amount" of an agent, as used herein, is an amount of such agent that is sufficient to bring about a desired result, especially upon administration of such agent to an animal or human.

The term "administration" is meant to include introduction of polypeptides or polynucleotides of the invention into an animal or human by any appropriate means known to the medical art, including, but not limited to, injection, oral, enteral, transdermal and parenteral (e.g., intravenous) administration.

The term "pharmaceutically acceptable salt" is intended to include salts of the mutant factor VIII or RAP of the invention. Such salts can be formed from pharmaceutically acceptable acids or bases, such as, for example, acids such as sulfuric, hydrochloric, nitric, phosphoric, etc., or bases such as alkali or alkaline earth metal hydroxides, ammonium hydroxides, alkyl ammonium hydroxides, etc.

The term "pharmaceutically acceptable composition" is intended to include solvents, carriers, diluents, and the like, which are utilized as additives or vehicles to preparations of the mutant factor VIII or RAP of the invention so as

to provide a carrier or adjuvant for the administration of such compounds to patients (human or animal) in need of the same. Such additives can perform certain functions, such as, for example, provide the proper ionic conditions for administration, stabilize the mutant factor VIII or RAP against inactivation or 5 degradation, and/or increase the half-life of the mutant factor VIII or RAP. A pharmaceutically acceptable composition is medically compatible with the host to which it is being administered.

10 The term "treatment" or "treating" is intended to include the administration of the pharmaceutically acceptable compositions of the invention comprising effective amounts of mutant factor VIII or RAP (polypeptides or polynucleotides) of the invention to a patient for purposes which may include prophylaxis, amelioration, prevention or cure of a medical disorder.

15 A material is said to be "substantially free of natural contaminants" if it has been substantially purified from materials with which it is normally and naturally found before such purification and those contaminants normally and naturally found with the substance *in vivo* or *in vitro* are substantially absent from the final preparation of the material. When administered to a subject in need of treatment, the mutant factor VIII or RAP of the invention is substantially free of natural contaminants which associate with the mutant factor VIII or RAP either 20 *in vivo* (in the host from which the mutant factor VIII or RAP was isolated), or *in vitro* (as a result of a chemical synthesis). By "substantially absent" is meant that such contaminants are either completely absent or are present at such low concentrations that their presence (1) does not interfere with the desired therapeutic effect of the active agent in the therapeutically acceptable composition 25 when such composition is administered to a patient in need of same and (2) does not harm the patient as the result of the administration of such composition.

Since current information indicates that the B domain has no known effect on factor VIII function, in some embodiments the B domain is deleted ("B domain (-)" or "B domainless") in the mutant factor VIII molecule or fragments

thereof ("B(-) factor VIII" or "B domainless factor VIII") prepared by any of the methods described herein.

Generation of mutant(s) with a prolonged lifetime may be a promising approach to increase the efficacy and reduce the cost of fVIII infusion therapy.

5 The invention provides methods of increasing the half-life of factor VIII by mutating factor VIII, and further provides methods of increasing the half-life of factor VIII using receptor-associated protein (RAP).

#### *Factor VIII Mutants: A2 Domain*

10 A recombinant mutant factor VIII having reduced receptor-dependent clearance and/or reduced receptor-independent clearance, and/or having superior coagulant activity, compared to human factor VIII, may be less expensive to make than plasma-derived factor VIII and may decrease the amount of factor VIII required for effective treatment of factor VIII deficiency.

15 The present invention provides active recombinant mutant factor VIII molecules or fragments thereof comprising at least one amino acid substitution in the A2 domain, polynucleotides encoding these, methods of producing and isolating them, and methods for characterizing their coagulant and plasma clearance properties.

20 The A2 domain is necessary for the procoagulant activity of the factor VIII molecule. Studies show that porcine factor VIII has six-fold greater procoagulant activity than human factor VIII (Lollar, P., and E. T. Parker 266 J. Biol. Chem. 12481-12486 (1991)), and that the difference in coagulant activity between human and porcine factor VIII appears to be based on a difference in amino acid sequence between one or more residues in the human and porcine A2 domains (Lollar, P., *et al.*, 267 J. Biol. Chem. 23652-23657 (1992)).

25 In one embodiment, the invention provides a method of increasing the half-life of factor VIII by substituting amino acids in the factor VIII A2 domain. In another embodiment, the invention provides mutant factor VIII and fragments thereof, and the polynucleotides encoding same, which have an increased

circulating half-life than human factor VIII. The increased circulating half-life is due to a reduction in receptor-dependent clearance of factor VIII. As shown in the examples, amino acids in the factor VIII A2 domain interact with at least one receptor that mediates A2 clearance and factor VIII clearance from plasma.

5        Thus, factor VIII mutants of the invention include mutants with one or more substitutions within the A2 domain. In a preferred embodiment, the factor VIII mutants have an amino acid substitution at one or more positions from 484 to 509. This region includes the following sequence: NH<sub>2</sub>- Arg Pro Leu Tyr Ser Arg Arg Leu Pro Lys Gly Val Lys His Leu Lys Asp Phe Pro Ile Leu Pro Gly Glu  
10        Ile Phe -COOH.

In another preferred embodiment, the factor VIII mutants have an amino acid substitution at one or more of positions 484, 489, 490, 493, 496 or 499.

15        The amino acid at a particular position is substituted with any of the 19 other naturally occurring amino acids. A2 amino acid substitutions of the invention are those that inhibit the interaction of factor VIII with its clearance receptor(s). Thus, nonconservative A2 amino acid substitutions are preferred over conservative substitutions. Conservative amino acid substitutions include, for example, the substitution of an acidic amino acid with another acidic amino acid, a basic amino acid with another basic amino acid, a hydrophobic amino acid with a another hydrophobic amino acid, a polar amino acid with another polar amino acid, or an aromatic amino acid with another aromatic amino acid.  
20        Conservative amino acid substitutions are well known in the art.

25        Thus, an example of a conservative substitution is the substitution of Lys with Arg, while an example of a preferred nonconservative substitution is the substitution of Lys with Asp, Glu, Tyr, Asn, Gln, Thr, Ser, Cys, Trp, Phe, Pro, Met, Val, Leu, Ile, Trp, Gly or Ala.

Preferred A2 amino acid substitutions of the invention are the substitution of Lys or Arg with Leu, Ile or Val. Additional preferred A2 amino acid substitutions of the invention are the substitutions of Lys or Arg with Asp or Glu.

Further preferred amino acid substitutions of the invention are the substitution of Lys or Arg with Ala, Ser, Thr, Met or Gly.

In another embodiment, amino acids at positions outside 484-509 are substituted, such as at positions 480, 481, 482, 483, 510, 511, 512 or 513. 5 Preferred substitutions at these positions are those that reduce receptor-dependent clearance of factor VIII, such as introducing bulky or negatively charged amino acids.

Specifically provided as an exemplary and a preferred embodiment is active recombinant human factor VIII having substituted amino acids in the A2 10 domain, the polynucleotide encoding it, and the methods of producing, isolating, and characterizing its activity. The methods by which this mutant is prepared can also be used to prepare active recombinant factor VIII or fragments thereof having substituted amino acids in domains other than A2. One skilled in the art will recognize that these methods also demonstrate how other recombinant mutant 15 factor VIII molecules or fragments thereof can be prepared in which amino acids are substituted. Additionally, recombinant methods are described in *Current Protocols in Molecular Biology*, F. M. Ausubel *et al.*, eds. (1991); and Sambrook, J., *et al.*, *Molecular Cloning. A Laboratory Manual*.

Mutant factor VIII is prepared starting with human cDNA (Biogen, Inc.) 20 encoding the factor VIII sequence. In a preferred embodiment, the factor VIII encoded by this cDNA includes domains A1-A2-A3-C1-C2, lacking the entire B domain, and corresponds to amino acid residues 1-740 and 1649-2332 of single chain human factor VIII (see SEQ ID NO:2), according to the numbering system of Wood *et al.*, 312 *Nature* 330-337 (1984).

25 The mutant factor VIII cDNA are cloned into expression vectors for ultimate expression of active factor VIII protein molecules in cultured cells by established techniques, as described by Selden, R.F., "Introduction of DNA into mammalian cells," in *Current Protocols in Molecular Biology*, F.M. Ausubel *et al.*, eds (1991).

In a preferred embodiment, a cDNA encoding mutant factor VIII is inserted in a mammalian expression vector, such as ReNeo, to form a mutant factor VIII construct. Preliminary characterization of the mutant factor VIII is accomplished by insertion of the mutant cDNA into the mammalian expression 5 vector and transient expression of the mutant protein in COS-7 cells. A determination of whether active protein is expressed can then be made. The expression vector construct is used further to stably transfect cells in culture, such as baby hamster kidney cells, using methods that are routine in the art, such as liposome-mediated transfection (Lipofectin<sup>TM</sup>, Life Technologies, Inc.). Expression of recombinant mutant factor VIII protein can be confirmed, for 10 example, by sequencing, Northern and Western blotting, or polymerase chain reaction (PCR). Mutant factor VIII protein in the culture media in which the transfected cells stably expressing the protein are maintained can be precipitated, pelleted, washed, and resuspended in an appropriate buffer, and the recombinant 15 mutant factor VIII protein purified by standard techniques, including immunaffinity chromatography using, for example, monoclonal anti-A2-Sepharose<sup>TM</sup>.

In a further embodiment, the mutant factor VIII comprising amino acid substitutions is expressed as a fusion protein from a recombinant molecule in 20 which sequence encoding a protein or peptide that enhances, for example, stability, secretion, detection, isolation, or the like is inserted in place adjacent to the factor VIII encoding sequence. Established protocols for use of homologous or heterologous species expression control sequences including, for example, promoters, operators, and regulators, in the preparation of fusion proteins are 25 known and routinely used in the art. (See *Current Protocols in Molecular Biology*, Ausubel, F.M., *et al.*, eds, Wiley Interscience, N.Y.)

Other vectors, including both plasmid and eukaryotic viral vectors, may 30 be used to express a recombinant gene construct in eukaryotic cells depending on the preference and judgment of the skilled practitioner (see, for example, Sambrook *et al.*, Chapter 16). Other vectors and expression systems, including

bacterial, yeast, and insect cell systems, can be used but are not preferred due to differences in, or lack of, glycosylation.

The purified mutant factor VIII or fragment thereof can be assayed for amount and for coagulation activity by standard assays including, for example, 5 the plasma-free factor VIII assay, the one-stage clotting assay, and the enzyme-linked immunosorbent assay using purified recombinant human factor VIII as a standard.

Recombinant mutant factor VIII protein can be expressed in a variety of 10 cells commonly used for culture and recombinant mammalian protein expression. A preferred cell line, available from the American Type Culture Collection, Rockville, Md., is baby hamster kidney cells, which are cultured using routine procedure and media.

Any mutant factor VIII construct having an amino acid substitution at one 15 or more positions in the A 2 domain as described can be assayed by standard procedures for coagulant activity and may be assayed for receptor-dependent clearance as described herein to identify mutant factor VIII molecules with enhanced coagulant activity and/or reduced receptor-mediated clearance. Mutant molecules may also be identified that have reduced coagulant activity compared to human or porcine factor VIII but also have reduced receptor-mediated 20 clearance. One skilled in the art will recognize that mutant factor VIII molecules or fragments thereof having less, equal, or greater coagulant activity, compared to human or porcine factor VIII, is useful for treating patients who have a factor VIII deficiency. The methods described herein to prepare active recombinant mutant factor VIII with amino acid substitution(s) in the A2 domain can be used 25 to prepare active recombinant mutant factor VIII protein with amino acid substitution(s) in the C2 domain or fragments thereof.

These molecules can be expressed in COS-7 cells and baby hamster 30 kidney cells as described above. They can be purified to homogeneity using methods known in the art, such as heparin-Sepharose™ and immunoaffinity chromatography. Protein concentration can be estimated by absorption of

ultraviolet light at  $A_{280}$ , and the specific activity of the constructs can be determined by dividing coagulant activity (measured in units per ml by single stage clotting assay) by  $A_{280}$ . Human factor VIII has a specific activity of approximately 3000-4000 U/ $A_{280}$ , whereas porcine factor VIII has a specific activity of approximately 20,000 U/ $A_{280}$ . In a preferred embodiment, the coagulant mutant factor VIII has a specific activity of 3000 U/ $A_{280}$ . In a preferred embodiment, the coagulant mutant factor VIII has a specific activity of 3000 U/ $A_{280}$ . The a specific activity of mutant factor VIII may be anywhere in the range of 1000-20,000 U/ $A_{280}$ .

As described herein, site-directed mutagenesis techniques are used to identify mutant protein with coagulant activity that can be enhanced, equal to, or reduced, compared to human factor VIII, but preferably is enhanced. Oligonucleotide-directed mutagenesis can be used as described in Kunkel, T.A., *et al.*, *Meth. Enzymol.* 204:125-139 (1991).

The mutant factor VIII proteins of the invention may have an amino acid substitution at one, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve, thirteen, fourteen, fifteen, sixteen, seventeen, eighteen, nineteen, twenty or more positions of factor VIII. The mutant factor VIII molecules of the invention may have amino acid substitutions in more than one domain, such as having an amino acid substitution both in the A2 domain and in the C2 domain.

The present invention contemplates that mutant factor VIII cDNA and protein can be characterized by methods that are established and routine, such as DNA sequencing, coagulant activity assays, mass by ELISA and by UV absorbency at 280 nm of purified mutant factor VIII, specific coagulant activity (U/mg), SDS-PAGE of purified mutant factor VIII, and the like. Other known methods of testing for clinical effectiveness may be required, such as amino acid, carbohydrate, sulfate, or metal ion analysis.

**Factor VIII Mutants: C2 Domain**

5        The same methods employed for preparing mutant human factor VIII having A2 domain amino acid substitution(s) can be used to prepare other recombinant mutant factor VIII protein and fragments thereof and the polynucleotides encoding these, such as mutant factor VIII having amino acid substitutions in the C2 domain.

10        Mutant human factor VIII molecules with amino acid substitution(s) in the C2 domain, which have reduced or no receptor-independent clearance can be identified. More specifically, the procedures can be the same or similar to those described herein for amino acid substitution in the A2 domain (by alanine scanning mutagenesis, site-directed mutagenesis, etc.,) substituting amino acids in the C2 domain of B (-) factor VIII; insertion into an expression vector, such as pBluescript; expression in cultured cells; and routine assay for coagulant activity and receptor-independent clearance.

15        In one embodiment, the invention provides mutant factor VIII and fragments thereof, and the polynucleotides encoding same, which have an increased circulating half-life than human factor VIII. The increased circulating half-life of mutant factor VIII is due to a reduction in receptor-independent clearance of factor VIII.

20        The C2 domain consists of amino acid residues 2173-2332. Within this 154 amino acid region, positions 2303-2332 are involved in both phospholipid binding and vWF binding. A synthetic peptide of factor VIII amino acids 2310-2320 (in which residues 2310 and 2320 are covalently linked) competes with factor VIII for phospholipid binding. A comparison of factor V, which does not bind vWF, and factor VIII reveals 5 amino acids within positions 2311-2319 that are unique to factor VIII. Although not being bound by any theory, these unique positions (Gln2311, Ser 2312, Val 2314, His2315 and Gln2316) are important for receptor-independent clearance, but are not critical for vWF binding.

25        Thus, one embodiment of the present invention is a mutant factor VIII having an amino acid substitution at one or more of positions 2173-2332 in the

C2 domain. In another preferred embodiment, the mutant factor VIII has an amino acid substitution at one or more positions 2311-2319 in the C2 domain.

The amino acid at a particular position is substituted with any of the 19 other naturally occurring amino acids. C2 amino acid substitutions of the 5 invention are those that inhibit the interaction of factor VIII with phospholipid. Thus, nonconservative C2 amino acid substitutions are preferred over conservative substitutions. Conservative amino acid substitutions include, for example, the substitution of an acidic amino acid with another acidic amino acid, a basic amino acid with another basic amino acid, a hydrophobic amino acid with 10 another hydrophobic amino acid, a polar amino acid with another polar amino acid, or an aromatic amino acid with another aromatic amino acid. Conservative amino acid substitutions are well known in the art.

Thus, an example of a conservative substitution is the substitution of Leu with Ile or Val, while an example of a preferred nonconservative substitution is 15 the substitution of Leu with Asp, Glu, Arg, Lys, His, Tyr, Asn, Gln, Thr, Ser, Cys, Trp, Phe, Pro, Met, Trp, Gly or Ala. One preferred substitution is Ala.

Additional embodiments of the present invention include a method of 20 treating hemophilia by administering a C2 domain mutant of factor VIII, pharmaceutically acceptable compositions comprising a C2 domain mutant of factor VIII either alone or in combination with RAP, and polynucleotides encoding a C2 domain mutant of factor VIII.

Furthermore, the amino acid substitution(s) in the C2 domain can be combined with amino acid substitution(s) in the A2 domain, to produce a mutant factor VIII with increased half-life.

#### 25 *Receptor Associated Protein*

A preferred embodiment of the present invention is directed to a method of increasing the half-life of factor VIII by administering RAP. Preferably, the RAP binds LRP, more preferably, the RAP has an increased affinity for LRP as compared to the naturally occurring RAP.

5 In another preferred embodiment of the present invention, RAP is a fragment, mutant or analog. Preferably, the RAP fragment, mutant or analog retains LRP binding activity. More preferably, the RAP fragment, mutant or analog has increased affinity for LRP as compared to the naturally occurring RAP.

In one embodiment, the RAP is a fragment having LRP binding activity. Such RAP fragments may comprise 10, 20, 30, 40, 50, 60, 75, 100, 125, 150, 175, 200, 250, 300 or 350 or more contiguous amino acids.

10 In one embodiment, RAP comprises amino acids 1 to 357 of Figure 4 (full-length RAP; amino acids -19 to 323 of SEQ ID NO:4). RAP contains a signal sequence 34 amino acids in length. Thus, in another embodiment, RAP comprises amino acids 35 to 357 of Figure 4 (mature RAP; amino acids 1 to 323 of SEQ ID NO:4.).

15 In another embodiment of the present invention, RAP contains an N-terminal or a C-terminal deletion, or a combination of N- and C-terminal deletions. N-terminal deletions often result in a protein with increased stability. Thus, for example, deleting between 1 and 50 amino acids from the N-terminus of mature RAP is useful to produce a more stable RAP. Therefore, additional embodiments of the present invention include, for example, RAP comprising 20 amino acids 36-357, 37-357, 38-357, 39-357, 40-357, 41-357, 42-357, 43-357, 44-357, 45-357, 46-357, 47-357, 48-357, 49-357, 50-357, 51-357, 52-357, 53-357, 54-357, 55-357, 56-357, 57-357, 58-357, 59-357, 60-357, 61-357, 62-357, 63-357, 64-357, 65-357, 66-357, 67-357, 68-357, 69-357, 70-357, 71-357, 72-357, 73-357, 74-357, 75-357, 76-357, 77-357, 78-357, 79-357, 80-357, 81-357, 25 82-357, 83-357, 84-357 and 85-357 of Figure 4 (positions 1-323, 2-323, 3-323, 4-323, 5-323, 6-323, 7-323, 8-323, 9-323, 10-323, 11-323, 12-323, 13-323, 14-323, 15-323, 16-323, 17-323, 18-323, 19-323, 20-323, 21-323, 22-323, 23-323, 24-323, 25-323, 26-323, 27-323, 28-323, 29-323, 30-323, 31-323, 32-323, 33-323, 34-323, 35-323, 36-323, 37-323, 38-323, 39-323, 40-323, 41-323, 42-323).

43-323, 44-323, 45-323, 46-323, 47-323, 48-323, 49-323 and 50-323 of SEQ ID NO:4).

5 The LDL receptor binding domain encompasses amino acids 237 to 353 of Figure 4 (amino acids 203 to 319 of SEQ ID NO:4). Thus, a preferred embodiment of the present invention is RAP comprising amino acids 237 to 353 (amino acids 203 to 319 of SEQ ID NO:4).

Another embodiment of the present invention is a polynucleotide encoding RAP.

10 In another embodiment of the present invention, RAP or a polynucleotide encoding RAP is used to treat hemophilia either alone or in combination with a factor VIII mutant.

Additional embodiments of the present invention include pharmaceutically acceptable compositions comprising RAP alone or in combination with one or more factor VIII mutants.

15 ***Pharmaceutically Acceptable Compositions***

20 Pharmaceutically acceptable compositions comprising mutant factor VIII or RAP, alone or in combination with appropriate pharmaceutical stabilization compounds, delivery vehicles, and/or carrier vehicles, are prepared according to known methods, as described in *Remington's Pharmaceutical Sciences* by E.W. Martin.

In one preferred embodiment, the preferred carriers or delivery vehicles for intravenous infusion are physiological saline or phosphate buffered saline.

25 In another preferred embodiment, suitable stabilization compounds, delivery vehicles, and carrier vehicles include but are not limited to other human or animal proteins such as albumin.

Phospholipid vesicles or liposomal suspensions are also preferred as pharmaceutically acceptable carriers or delivery vehicles. These can be prepared according to methods known to those skilled in the art and can contain, for example, phosphatidylserine/phosphatidylcholine or other compositions of

phospholipids or detergents that together impart a negative charge to the surface, since factor VIII binds to negatively charged phospholipid membranes. Liposomes may be prepared by dissolving appropriate lipid(s) (such as stearoyl 5 phosphatidyl ethanolamine, stearoyl phosphatidyl choline, arachadoyl phosphatidyl choline, and cholesterol) in an inorganic solvent that is then evaporated, leaving behind a thin film of dried lipid on the surface of the container. An aqueous solution of the mutant factor VIII or RAP is then introduced into the container. The container is then swirled by hand to free lipid material from the sides of the container and to disperse lipid aggregates, thereby 10 forming the liposomal suspension.

Mutant factor VIII or RAP can be combined with other suitable stabilization compounds, delivery vehicles, and/or carrier vehicles, including 15 vitamin K dependent clotting factors, tissue factor, and von Willebrand factor (vWF) or a fragment of vWF that contains the factor VIII binding site, and polysaccharides such as sucrose.

Mutant factor VIII can be stored bound to vWF to increase the shelf-life 20 of the mutant molecule. Additionally, lyophilization of factor VIII can improve the yield of active molecules in the presence of vWF. Lyophilization can also improve the yield of RAP. Current methods for storage of human and animal factor VIII used by commercial suppliers can be employed for storage of mutant 25 factor VIII or RAP. These methods include: (1) lyophilization of factor VIII in a partially-purified state (as a factor VIII "concentrate" that is infused without further purification); (2) immunoaffinity-purification of factor VIII by the Zimmerman method and lyophilization in the presence of albumin, which stabilizes the factor VIII; (3) lyophilization of recombinant factor VIII in the presence of albumin.

Additionally, factor VIII has been indefinitely stable at 4°C in 0.6 M NaCl, 20 mM MES, and 5 mM CaCl<sub>2</sub> at pH 6.0 and also can be stored frozen in these buffers and thawed with minimal loss of activity.

***Methods of Treatment***

Mutant factor VIII or RAP is used to treat uncontrolled bleeding due to factor VIII deficiency (e.g., intraarticular, intracranial, or gastrointestinal hemorrhage) in hemophiliacs with and without inhibitory antibodies and in 5 patients with acquired factor VIII deficiency due to the development of inhibitory antibodies. The active materials are preferably administered intravenously.

Factor VIII is classically defined as that substance present in normal blood plasma that corrects the clotting defect in plasma derived from individuals with hemophilia A. The coagulant activity *in vitro* of purified and partially-purified 10 forms of factor VIII is used to calculate the dose of factor VIII for infusions in human patients and is a reliable indicator of activity recovered from patient plasma and of correction of the *in vivo* bleeding defect. There are no reported discrepancies between standard assay of novel factor VIII molecules *in vitro* and their behavior in the dog infusion model or in human patients, according to 15 Lusher, J. M., *et al.*, *New. Engl. J. Med.* 328:453-459 (1993); Pittman, D. D., *et al.*, *Blood* 79:389-397 (1992), and Brinkhous *et al.*, *Proc. Natl. Acad. Sci.* 82:8752-8755 (1985).

Usually, the desired plasma factor VIII level to be achieved in the patient 20 through administration of the mutant factor VIII is in the range of 30-100% of normal. In a preferred mode of administration of the mutant factor VIII, the composition is given intravenously at a preferred dosage in the range from about 5 to 50 units/kg body weight, more preferably in a range of 10-50 units/kg body weight; and most preferably at a dosage of 20-40 units/kg body weight; the 25 interval frequency is in the range from about 8 to 24 hours (in severely affected hemophiliacs); and the duration of treatment in days is in the range from 1 to 10 days or until the bleeding episode is resolved. See, e.g., Roberts, H. R., and M. R. Jones, "Hemophilia and Related Conditions - Congenital Deficiencies of Prothrombin (Factor II, Factor V, and Factors VII to XII)," Ch. 153, 1453-1474, 1460, in *Hematology*, Williams, W. J., *et al.*, ed. (1990).

Administration of an effective amount of RAP will result in similar levels of factor VIII in patient blood as indicated above. Patients with inhibitors may require more mutant factor VIII, or patients may require less mutant factor VIII because of its higher specific activity than human factor VIII or increased plasma 5 half-life. Likewise, patients may require more or less RAP, depending on RAP's binding affinity to LRP or other factor VIII clearance receptor, or depending on its stability in circulating blood. As in treatment with human or porcine factor 10 VIII, the amount of mutant factor VIII or RAP infused is defined by the one-stage factor VIII coagulation assay and, in selected instances, *in vivo* recovery is determined by measuring the factor VIII in the patient's plasma after infusion. It 15 is to be understood that for any particular subject, specific dosage regimens should be adjusted over time according to the individual need and the professional judgment of the person administering or supervising the administration of the compositions, and that the concentration ranges set forth herein are exemplary only and are not intended to limit the scope or practice of the claimed composition.

#### *Administration*

In a preferred embodiment, pharmaceutically acceptable compositions of mutant factor VIII or RAP alone or in combination with stabilizers, delivery 20 vehicles, and/or carriers are infused into patients intravenously according to the same procedure that is used for infusion of human or animal factor VIII.

The treatment dosages of mutant factor VIII or RAP composition that must be administered to a patient in need of such treatment will vary depending 25 on the severity of the factor VIII deficiency. Generally, dosage level is adjusted in frequency, duration, and units in keeping with the severity and duration of each patient's bleeding episode. Accordingly, the mutant factor VIII or RAP is included in the pharmaceutically acceptable carrier, delivery vehicle, or stabilizer in an amount sufficient to deliver to a patient a therapeutically effective amount of the mutant protein to stop bleeding, as measured by standard clotting assays.

Treatment can take the form of a single intravenous administration of the composition or periodic or continuous administration over an extended period of time, as required. Alternatively, mutant factor VIII or RAP can be administered subcutaneously or orally with liposomes in one or several doses at varying 5 intervals of time. Mutant factor VIII or RAP can also be used to treat uncontrolled bleeding due to factor VIII deficiency in hemophiliacs who have developed antibodies to human factor VIII.

Suitable examples of sustained-release preparations include semipermeable matrices of solid hydrophobic polymers containing the protein, 10 which matrices are in the form of shaped articles, e.g. films, or microcapsules. Examples of sustained-release matrices include polyesters, hydrogels, e.g., poly(2-hydroxyethyl-methacrylate) as described by Langer *et al.*, *J. Biomed. Mater. Res.* 15:167-277 (1981) and Langer, *Chem. Tech.* 12: 98-105 (1982) or poly(vinylalcohol), polylactides (U.S. Pat. No. 3,773,919, EP 58,481), 15 copolymers of L-glutamic acid and gamma ethyl-L-glutamate (Sidman *et al.*, *Biopolymers* 22:547-556 (1983)), non-degradable ethylene-vinyl acetate (Langer *et al.*, *supra*), degradable lactic acid-glycolic acid copolymers such as the Lupron Depot<sup>TM</sup> (injectable microspheres composed of lactic acid-glycolic acid copolymer and leuprolide acetate), and poly-D-(-)-3-hydroxybutyric acid (EP 20 133,988). While polymers such as ethylene-vinyl acetate and lactic acid-glycolic acid enable release of molecules for over 100 days, certain hydrogels release 20 proteins for shorter time periods. When encapsulated proteins remain in the body for a long time, they may denature or aggregate as a result of exposure to moisture at 37 °C, resulting in a loss of biological activity and possible changes in 25 immunogenicity. Rational strategies can be devised for protein stabilization depending on the mechanism involved. For example, if the aggregation mechanism is discovered to be intermolecular S-S bond formation through thio-disulfide interchange, stabilization can be achieved by modifying sulphhydryl residues, lyophilizing from acidic solutions, controlling moisture content, using 30 appropriate additives, and developing specific polymer matrix compositions.

Sustained-release blood factor compositions also include liposomally entrapped blood factor or antibody. Liposomes containing the claimed blood factor or antibody are prepared by methods known per se: DE 3,218,121; Epstein *et al.*, Proc. Natl. Acad. Sci. USA, 82: 3688-3692 (1985); Hwang *et al.*, Proc. Natl. Acad. Sci. USA, 77: 4030-4034 (1980); EP 52,322; EP 36,676; EP 88,046; EP 143,949; EP 142,641; Japanese patent application 83-118008; U.S. Pat. No. 4,485,045 and 4,544,545; and EP 102,324. Ordinarily the liposomes are of the small (about 200-800 Angstroms) unilamellar type, the selected proportion being adjusted for the optimal blood factor therapy. Liposomes with enhanced circulation time are disclosed in U.S. Pat. No. 5,013,556. Additionally, Giles, A. R., *et al. Brit. J. Hematol.* 69:491-497 (1988) describe the formulation of factor Xa in phosphatidylcholine-phosphatidylserine vesicles.

15 Additionally, mutant factor VIII or RAP can be administered by transplant of cells genetically engineered to produce the protein or by implantation of a device containing such cells, as described below.

Gene Therapy

Polynucleotides encoding the mutant factor VIII or RAP may be employed in accordance with the present invention by expression of such mutant factor VIII or RAP *in vivo*, in treatment modalities often referred to as "gene therapy."

20                   Mutant factor VIII or RAP can also be delivered by gene therapy in the same way that human factor VIII can be delivered, using delivery means such as retroviral vectors. This method consists of incorporation of factor VIII cDNA into human cells that are transplanted directly into a factor VIII deficient patient or that are placed in an implantable device, permeable to the factor VIII molecules but impermeable to cells, that is then transplanted. The preferred method will be 25 retroviral-mediated gene transfer. In this method, an exogenous gene (e.g., a factor VIII cDNA) is cloned into the genome of a modified retrovirus. The gene/cDNA is inserted into the genome of the host cell by viral machinery where it will be expressed by the cell. The retroviral vector is modified so that it will

not produce virus, preventing viral infection of the host. The general principles for this type of therapy are known to those skilled in the art and have been reviewed in the literature (e.g., Kohn, D.B., and P.W. Kantoff, *Transfusion* 29:812-820 (1989)).

5        Thus, for example, cells from a patient may be engineered with a polynucleotide, such as a DNA or RNA, encoding a polypeptide *ex vivo*, and the engineered cells then can be provided to a patient to be treated with the polypeptide. For example, cells may be engineered *ex vivo* by the use of a retroviral plasmid vector containing RNA encoding a polypeptide of the present  
10      invention. Such methods are well-known in the art and their use in the present invention will be apparent from the teachings herein.

15      Similarly, cells may be engineered *in vivo* for expression of a polypeptide *in vivo* by procedures known in the art. For example, a polynucleotide of the invention may be engineered for expression in a replication defective retroviral vector, as discussed above. The retroviral expression construct then may be isolated and introduced into a packaging cell is transduced with a retroviral plasmid vector containing RNA encoding a polypeptide of the present invention such that the packaging cell now produces infectious viral particles containing the gene of interest. These producer cells may be administered to a patient for  
20      engineering cells *in vivo* and expression of the polypeptide *in vivo*. These and other methods for administering a polypeptide of the present invention by such method should be apparent to those skilled in the art from the teachings of the present invention.

25      Retroviruses from which the retroviral plasmid vectors herein above mentioned may be derived include, but are not limited to, Moloney Murine Leukemia Virus, spleen necrosis virus, retroviruses such as Rous Sarcoma Virus, Harvey Sarcoma Virus, avian leukosis virus, gibbon ape leukemia virus, human immunodeficiency virus, adenovirus, Myeloproliferative Sarcoma Virus, and mammary tumor virus. In one embodiment, the retroviral plasmid vector is  
30      derived from Moloney Murine Leukemia Virus.

Such vectors will include one or more promoters for expressing the polypeptide. Suitable promoters which may be employed include, but are not limited to, the retroviral LTR; the SV40 promoter; and the human cytomegalovirus (CMV) promoter described in Miller *et al.*, *Biotechniques* 7: 5 980-990 (1989), or any other promoter (e.g., cellular promoters such as eukaryotic cellular promoters including, but not limited to, the histone, RNA polymerase III, and  $\beta$ -actin promoters). Other viral promoters which may be employed include, but are not limited to, adenovirus promoters, thymidine kinase (TK) promoters, and B19 parvovirus promoters. The selection of a suitable promoter will be 10 apparent to those skilled in the art from the teachings contained herein.

The retroviral plasmid vector is employed to transduce packaging cell lines to form producer cell lines. Examples of packaging cells which may be transfected include, but are not limited to, the PE501, PA317, Y-2, Y-AM, PA12, T19-14X, VT-19-17-H2, YCRE, YCRIP, GP+E-86, GP+envAm12, and DAN 15 cell lines as described in Miller, A., *Human Gene Therapy* 1:5-14 (1990). The vector may be transduced into the packaging cells through any means known in the art. Such means include, but are not limited to, electroporation, the use of liposomes, and  $\text{CaPO}_4$  precipitation. In one alternative, the retroviral plasmid vector may be encapsulated into a liposome, or coupled to a lipid, and then 20 administered to a host.

The producer cell line will generate infectious retroviral vector particles, which include the polynucleotide(s) encoding the polypeptides. Such retroviral vector particles then may be employed to transduce eukaryotic cells, either *in vitro* or *in vivo*. The transduced eukaryotic cells will express the 25 polynucleotide(s) encoding the polypeptide. Eukaryotic cells which may be transduced include, but are not limited to, embryonic stem cells, embryonic carcinoma cells, as well as hematopoietic stem cells, hepatocytes, fibroblasts, myoblasts, keratinocytes, endothelial cells, and bronchial epithelial cells.

The following examples are illustrative only and are not intended to limit 30 the scope of the invention as defined by the appended claims. It will be apparent

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to those skilled in the art that various modifications and variations can be made in the methods of the present invention without departing from the spirit and scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

All patents, publications and publicly available sequences referred to herein are expressly incorporated by reference.

### *Examples*

#### *Example 1*

10

Activated factor VIII (fVIIIa) functions in the intrinsic pathway of blood coagulation as a cofactor for factor IXa in the conversion of factor X to activated factor X (Xa). When IXa is bound to membrane and fVIII the rate of factor X to IXa conversion increases 100,000-1,000,000 fold. The procoagulant activity of fVIIIa is regulated by rapid and potentially reversible dissociation of the A2 subunit from the A1/A3C1C2 dimer and by activated protein C (APC) proteolysis of the residual fVIIIa. Removal of the A2 and A1/A3C1C2 fragments is an additional *in vivo* mechanism to control factor VIIIa activity at the site of blood coagulation.

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We tested this in a model system using mouse embryonic fibroblasts (MEF) that express low density lipoprotein receptor related protein (LRP) a multi ligand endocytic receptor and PEA 13 fibroblasts that are genetically deficient in LRP. Using the above model system we studied the mechanisms of cellular uptake and degradation of thrombin activated fVIII subunits to evaluate the role of these mechanisms in regulation of fVIIIa level.

***Methods***

**Cell mediated ligand internalization and degradation assays.** Cells were seeded into 24 well dishes and allowed to grow for 24 hours at 37°C. 5% CO<sub>2</sub> MEF and PEA 13 cells were incubated for selected time intervals at 37°C with 5 <sup>125</sup>I-labeled fVIIIa fragments in the presence and absence of unlabeled competitors as described in the figure legends. Radioactivity appearing in the cell culture medium that was soluble after precipitation with 10% trichloroacetic acid (TCA) was taken to represent degraded ligand. Total ligand degradation was corrected by subtracting the amount of 10% TCA soluble radioactivity occurred in control 10 wells lacking cells. The amount of labeled ligand bound to the cell surface or that was internalized by cells was determined as follows. Cells were washed with cold phosphate buffered saline and treated with a trypsin EDTA proteinase K solution. Surface bound material was defined as the amount of radioactive ligand released by this treatment and the amount of internalized ligand was defined as 15 the amount of radioactivity which remained associated with the cell pellet following the treatment.

**Determining of the A2 affinity for LRP.** LRP (3.5 µg/ml) in 0.1 M NaHCO<sub>3</sub>, pH 9.6 was incubated in Immulon I microtiter well strips for 16 hours at 4°C. After washing with TBS, 5 mM CaCl<sub>2</sub>, 0.05% Tween 20 buffer (TBS-T) and 20 blocking with 3% BSA, <sup>125</sup>I-A2 (5 nM) and increasing concentrations unlabeled A2 (0-1750 nM) were added. Following the incubation for 1 hour at 37°C and washing with TBS-T, the radioactivity bound to the wells was counted. <sup>125</sup>I-A2 binding in the presence of unlabeled A2 was plotted using the computer program "Ligand." The K<sub>d</sub> value for A2/LRP binding was calculated from the 25 displacement curve, showing a best fit of the data to a single class of sites.

**Effect of RAP on the clearance of <sup>125</sup>I-A2 domain from the plasma of mice.** To elucidate the role of LRP receptor in the clearance of the A2 domain from

5 plasma *in vivo* we tested the plasma level of  $^{125}\text{I}$ -labeled A2 in the presence and absence of RAP after tail vein injection in mice. 250  $\mu\text{l}$  samples of A2 (36 nM), in the presence and absence of RAP (267  $\mu\text{M}$ ) were injected into the tail vein of BALB/c mice. At the indicated times, blood (50  $\mu\text{l}$ ) was collected into 10  $\mu\text{l}$  of 0.5 M EDTA and counted for its  $^{125}\text{I}$  content. RAP significantly delays the plasma elimination of A2 domain. This experiment indicates that a RAP dependent hepatic receptor, LRP, plays a major role in the removal of A2 from circulation.

10 15 **LRP receptor mediated internalization and degradation of the  $^{125}\text{I}$ -A2 domain by fibroblast cells.** The cellular uptake and degradation of activated factor VIII fragments was studied using mouse embryonic fibroblast (MEF) cells expressing low density lipoprotein receptor - related protein (LRP), a multi ligand endocytic receptor, and PEA 13 cells represents fibroblasts lacking LRP. The fVIIIa subunits interaction with MEF and PEA 13 cells represent an adequate model for *in vivo* processes because fibroblast cells became exposed to coagulation site upon vascular injury. LRP mediated internalization and degradation of some proteins (Thrombin:ATIII complex and other complexes of thrombin with inhibitors, tissue factor pathway inhibitor involved in coagulation cascade is known.

20 25  $^{125}\text{I}$ -A2 (10 nM) was incubated with cells for several times and amount of surface bound, internalized and degraded  $^{125}\text{I}$ -labeled protein were determined as described under "Methods." The A2 domain was internalized and degraded by MEF cells but not by PEA 13 cells suggesting that expression of LRP receptor is required for these processes. The internalization and degradation of A2 was blocked by RAP, an inhibitor of LRP binding to its ligands.

**Internalization of the  $^{125}\text{I}$ -A2 and APC cleaved A2 domain, by LRP presenting MEF cells and control PEA 13 cells, lacking LRP.** Inactivation of fVIIIa by APC leads to a cleavage of the A2 at Arg<sup>562</sup>. Since cofactor activity

cannot be reconstituted from A2<sub>N</sub>/A2<sub>C</sub> and Al/A3C1C2 dimer, we proposed that A2<sub>N</sub>/A2<sub>C</sub> removal from circulation may occur by a mechanism different than that for intact A2. To examine the effect of proteolysis by APC on cellular internalization of the A2 domain, we compared the <sup>125</sup>I-A2 and <sup>125</sup>I-A2<sub>N</sub>/A2<sub>C</sub> 5 uptake by MEF and PEA 13 cells. We found that in contrast to A2 domain, the internalization of <sup>125</sup>I-A2<sub>N</sub>/A2<sub>C</sub> is not mediated by LRP receptor.

10 **Binding the A2 domain to the immobilized LRP.** To the microtiter wells with immobilized LRP <sup>125</sup>I-A2 (5 nM) and increasing concentrations of unlabeled A2 (0-1750 nM) were added. After incubation for 1 hour at 37°C the wells were washed with TBS-T and radioactivity bound to the wells was counted. <sup>125</sup>I-A2 binding in the presence of unlabeled A2 is expressed as the percentage of <sup>125</sup>I-A2 binding, when no competitor was added. The data was analyzed using the computer program "Ligand". The K<sub>d</sub> value for A2/ LRP binding calculated from the displacement data was 130 nM.

15 **Internalization of <sup>125</sup>I-labeled Al/A3C1C2 and Al<sup>336</sup>/A3C1C2 by fibroblast cells.** We proposed that phospholipid binding site previously localized to the C2 domain of fVIII light chain mediates the cellular surface binding and internalization of Al/A3C1C2 and Al<sup>336</sup>/A3C1C2 dimers. To test this hypothesis we determined internalization <sup>125</sup>I-Al/A3C1C2 and <sup>125</sup>I-Al<sup>336</sup>/A3C1C2 by MEF 20 cells in the presence and absence of anti-C2 domain monoclonal antibody NMC-VIII/5, which blocks the membrane binding sites of the C2 domain.

25 Wells containing 2x10<sup>5</sup> MEF cells were incubated with 3 nM of <sup>125</sup>I-Al/A3C1C2 or 3 nM of <sup>125</sup>I-Al<sup>336</sup>/A3C1C2 at 37°C in the presence or absence of 30 nM monoclonal antibody NMC-VIII/5. In the control experiments, PEA 13 cells lacking LRP were incubated as above with <sup>125</sup>I-Al/A3C1C2 and <sup>125</sup>I-Al<sup>336</sup>/A3C1C2. At several times internalization of the dimers was described under "Methods."

5 Since internalization of both  $^{125}\text{I}$ -A1/A3C1C2 and  $^{125}\text{I}$ -A1 $^{336}$ /A3C1C2 dimers was completely inhibited by monoclonal antibody NMC-VIII/5, that recognizes the membrane binding site of fVIII C2 domain, we concluded that membrane binding of C2 is a critical step required for internalization of the above dimers. The rate of internalization was similar for MEF and PEA 13 cells, which indicates that LRP receptor is not involved in this process.

10 **Degradation of  $^{125}\text{I}$ -A1/A3C1C2 and  $^{125}\text{I}$ -A1 $^{336}$ /A3C1C2 by MEF cells.** MEF cells were incubated with  $^{125}\text{I}$ -A1/A3C1C2 (3 nM) or  $^{125}\text{I}$ -A1 $^{336}$ /A3C1C2 (3 nM) for 22 hours at 37°C in the presence and absence PAP (1  $\mu\text{M}$ ). The degradation of dimers was measured as described under "Methods".

15 The degradation of A1/A3C1C2 dimer is RAP dependent. In contrast, degradation of APC cleaved A1 $^{336}$ /A3C1C2 dimer is RAP independent and does not correlate with LRP expression.

### ***Conclusions***

15 The A2 domain was internalized and degraded by mouse embryonic fibroblasts (MEF) which are expressing low density lipoprotein receptor - related protein (LRP), a multi ligand endocytic receptor. The internalization and degradation of A2 was blocked by RAP, an inhibitor of LRP binding to its ligands. *In vivo* clearance studies in mice demonstrated that RAP inhibited the 20 clearance of  $^{125}\text{I}$ -A2 from circulation. The radioactivity was preferentially accumulated in liver in the absence but not in the presence of RAP. This indicate that a RAP sensitive hepatic receptor most likely LRP, plays a major role in the removal of  $^{125}\text{I}$ -A2 from the circulation.

25 The phospholipid binding site previously localized to the C2 domain of fVIII light chain mediates the cellular membrane binding and internalization of A1/A3C1C2 and A1 $^{336}$ /A3C1C2 dimers.

5 LRP receptor does not participate in cellular uptake and degradation of fragments A2<sub>N</sub>/A2<sub>C</sub> and A1<sup>336</sup>/A3C1C2, produced by irreversible inactivation of fVIIIa by APC. A2 and A1/A3C1C2 fragments produced by reversible inactivation of fVIIIa are removed by LRP-mediated and LRP-independent mechanisms, respectively. LRP is involved in the regulation of coagulation processes *in vivo*, by removal of A2 domain and A1/A3C1C2 dimer, the fragments from which active factor VIIIa can be reconstituted.

#### *Example 2*

10 The plasma glycoprotein factor VIII (fVIII) serves as a cofactor for the factor X activation complex in the intrinsic pathway of blood coagulation. FVIII circulates in plasma in a tight noncovalent complex with its carrier protein von Willebrand factor (vWF). Although the complex formation of fVIII with vWF is critical for maintenance of a normal half-life and level of fVIII in circulation, the mechanisms associated with fVIII turnover are not well defined. In the present 15 study, we found that catabolism of fVIII is mediated by the low density lipoprotein receptor-related protein/α<sub>2</sub>-macroglobulin receptor (LRP), a liver endocytic, receptor responsible for *in vivo* clearance of a number of structurally unrelated ligands. A specific binding between fVIII and LRP was demonstrated by homologous ligand competition experiments, where a K<sub>d</sub> of 116 nM was 20 determined for fVIII binding to LRP. A 39 kDa receptor-associated protein (RAP), an antagonist of ligand binding by LRP, completely inhibited fVIII binding to purified LRP. The region of fVIII involved in its binding to LRP was localized to the A2 domain residues 484-509, based on the ability of the isolated A2 domain and the synthetic A2 domain peptide 484-509 to prevent fVIII 25 interaction with LRP. Since vWF did not inhibit fVIII binding to LRP, we proposed that LRP receptor may internalize fVIII from its complex with vWF. In agreement with this, mouse embryonic fibroblasts (MEF) that express LRP, but not fibroblasts genetically deficient in LRP (PEA 13), were able to internalize and

degrade  $^{125}\text{I}$ -fVIII/vWf complex. The latter processes were competed by RAP and A2 subunit of fVIII, indicating that cellular internalization and subsequent degradation were mediated by interaction of the A2 domain of fVIII with LRP. MEF cells were not able to internalize  $^{125}\text{I}$ -vWf from  $^{125}\text{I}$ -vWf /fVIII complex. 5 This indicates that vWf does not follow fVIII in the LRP-mediated pathway and dissociates from fVIII at the early stage of endocytosis. *In vivo* clearance studies of  $^{125}\text{I}$ -fVIII/vWf complex in mice demonstrated that RAP prolonged the half-life of  $^{125}\text{I}$ -fVIII in circulation by 2.5-fold, indicating that RAP-sensitive receptor, most likely LRP, is responsible for the plasma clearance of fVIII.

10 ***Introduction***

The plasma glycoprotein factor VIII (fVIII) functions as a cofactor for the factor X activation enzyme complex in the intrinsic pathway of blood coagulation, and it is decreased or nonfunctional in patients with hemophilia A. The fVIII protein consists of a homologous A and C domains and a unique B domain which are arranged in the order A1-A2-B-A3-C1-C2 (Vehar, G.A., *et al.*, 15 *Nature* 312:337-340 (1984)). It is processed to a series of  $\text{Me}^{2+}$  linked heterodimers produced by cleavage at the B-A3 junction (Fay, P. J., *et al.*, *Biochem. Biophys. Acta* 871:268-278 (1986)), generating a light chain (LCh) consisting of an acidic region (AR) and A3, C1, and C2 domains and a heavy 20 chain (HCh) which consists of the A1, A2, and B domains (Fig. 1).

Transplantational studies both in animals and in humans demonstrated that the liver hepatocytes are the major fVIII-producing cells (Lewis, J. H., *et al.*, *N. Engl. J. Med* 312:1189-1191 (1985); Bontempo, F. A., *et al.*, *Blood* 69:1721-1724 (1987)). Immediately after release into circulation, fVIII binds with high affinity ( $K_d < 0.5$  nM (MacGregor, I.R., *et al.*, *Vox. Sang.* 69:319-327 (1995); 25 Saenko, E.L. and Scandella, D., *J. Biol Chem* 272:18007-18014 (1995)) to its carrier protein vWf to form a tight, noncovalent complex, which is required for maintenance of a normal fVIII level in the circulation. Complex formation with

vWf stabilizes association of the LCh and HCh within fVIII molecule (Wise, R.J., *et al.*, *J. Biol. Chem.* 266:21948-21955 (1991)) and prevents fVIII from C2-domain mediated binding to phospholipid membranes (Gilbert, G.E., *et al.*, *J. Biol. Chem.* 267:15861-15868 (1992)), activation by activated factor X (Koppelman, S.J., *et al.*, *J. Lab. Clin. Med.* 123:585-593 (1994)) and from protein C-catalyzed inactivation (Fay, P.J., *et al.*, *J. Biol. Chem.* 266:2172-2177 (1991)). vWf comprises a series of high molecular weight, disulfide-bonded multimers with molecular weight values as high as  $2 \times 10^7$  Da (Hoyer, L.W. and Shainoff, J.R., *Blood* 55:1056-1059 (1980)) and circulates in plasma at 10  $\mu\text{g}/\text{ml}$  or 50 nM, assuming a molecular mass of 270 kDa for vWf monomers (Girma, J.-P., *et al.*, *Biochemistry* 25:3156-3163 (1986)). Since the concentration of fVIII in plasma is approximately 1 nM (Wion, K., *et al.*, *Nature* 317:726-730 (1985)), one fVIII molecule is bound per 50 vWf monomers (Vlot, A.J., *et al.*, *Blood* 85:3150-3157 (1995)).

Activation of fVIII by thrombin leads to dissociation of activated fVIII (fVIIIa) from vWf and to at least 100-fold increase of the cofactor activity. The fVIIIa is a A1/A2/A3-C1-C2 heterotrimer (Fay, P.J., *et al.*, *J. Biol. Chem.* 266:8957-8962 (1991)) in which domains A1 and A3 retain the metal ion linkage (Fig. 1) and the stable dimer A1/A3-C1-C2 is weakly associated with the A2 subunit through electrostatic forces (Fay, P.J., *et al.*, *J. Biol. Chem.* 266:8957-8962 (1991)). Spontaneous dissociation of the A2 subunit from the heterotrimer results in non-proteolytic inactivation of fVIIIa.

Infusion of fVIII/vWf complex or purified plasma or recombinant fVIII into patients with severe hemophilia A who do not have fVIII (Fijnvandraat, K., *et al.*, *Thromb. Haemostas.* 77:298-302 (1997); Morfini, M., *et al.*, *Thromb. Haemostas.* 68:433-435 (1992)) or in normal individuals (Over, J., *et al.*, *J. Clin. Invest.* 62:223-234 (1978)) results in a similar fVIII disappearance with a half-life of 12-14 hours. Although the complex between fVIII and vWf is crucial for normal half-life and level of fVIII in the circulation, the mechanisms associated with turnover of fVIII/vWf complex are not well defined. We proposed that

fVIII/vWF complex is eliminated from plasma via clearance receptor and tested the possibility that this receptor is low density lipoprotein related protein receptor (LRP). Cellular endocytosis mediated by LRP was shown to be a mechanism of removal of a number of structurally unrelated ligands including several proteins related to coagulation or fibrilolysis. These ligands are: complexes of thrombin with antithrombin III (ATIII), heparin cofactor II (HCII) (Kounnas, M.Z., *et al.*, *J. Biol. Chem.* 271:6523-6529 (1996)), protease nexin I (Knauer, M.F., *et al.*, *J. Biol. Chem.* 272:12261-12264 (1997)), complexes of urokinase-type and tissue-type plasminogen activators (u-PA and t-PA, respectively) with plasminogen activator inhibitor (PAI-1) (Nykjaer, A., *et al.*, *J. Biol. Chem.* 267:14543-14546 (1992); Orth, K., *et al.*, *Proc. Natl. Acad. Sci.* 89:7422-7426 (1992)), thrombospondin (Mikhailenko, I., *et al.*, *J. Biol. Chem.* 272:6784-6791 (1997)), tissue factor pathway inhibitor (TFPI) (Warshawsky, I., *et al.*, *Proc. Natl. Acad. Sci.* 91:6664-6668 (1994)), and factor Xa (Narita, M., *et al.*, *Blood* 91:555-560 (1998); Ho, G., *et al.*, *J. Biol. Chem.* 271:9497-9502 (1996)).

LRP, a large cell-surface glycoprotein identical to  $\alpha_2$ -macroglobulin receptor (Strickland, D.K., *et al.*, *J. Biol. Chem.* 265:17401-17404 (1990)), is a member of the low density lipoprotein (LDL) receptor family which also includes the LDL receptor, very low density lipoprotein (VLDL) receptor, vitellogenin receptor and glycoprotein 330 receptor. LRP receptor consists of the non-covalently linked 515 kDa  $\alpha$ -chain (Herz, J., *et al.*, *EMBO J.* 7:4119-4127 (1988)) containing binding sites for LRP ligands, and the 85 kDa transmembrane  $\beta$ -chain. Within the  $\alpha$ -chain, cluster of cysteine-rich class A repeats is responsible for ligand binding (Moestrup, S.K., *et al.*, *J. Biol. Chem.* 268:13691-13696 (1993)). In contrast to the acidic ligand binding region in LRP, its ligands expose regions rich in positively charged amino acid residues (Moestrup, S.K., *Biochim. Biophys. Acta* 1197:197-213 (1994)). This type of binding and 31 class A repeats present in LRP may be responsible for its wide ligand diversity and ability to serve as a multi-ligand clearance receptor. LRP is expressed in many cell types and tissues including placenta, lung and brain (Moestrup, S.K., *et al.*, *Cell Tissue Res.*

269:375-382 (1992)) and is a major endocytic receptor in the liver (Strickland, D.K., *et al.*, *FASEB J.* 9:890-898 (1995)). A 39 kDa receptor-associated protein (RAP) binds to LRP with high affinity ( $K_d$ =4 nM (27)) and inhibits binding and LRP-mediated internalization and degradation of all ligands (Moestrup, S.K. *Biochim. Biophys. Acta* 1197:197-213 (1994); Williams, S.E., *et al.*, *J. Biol. Chem.* 267:9035-9040 (1992)), therefore serving as a useful tool for testing whether LRP is involved in endocytosis of a given ligand.

5 In the present study we demonstrated that fVIII specifically binds to LRP, and that LRP mediates the internalization and subsequent degradation of fVIII in  
10 cultured fibroblasts and appears to be responsible for *in vivo* clearance of fVIII from circulation. We also demonstrated that interaction of the A2 domain of fVIII with LRP is responsible for mediating catabolism of fVIII.

#### ***Experimental Procedures***

15 **Monoclonal Antibodies.** The monoclonal antibodies (mAbs) C4 (epitope within the fVIII light chain residues 1670-1684 (Foster, P.A., *et al.*, *J. Biol. Chem.* 263:5230-5234 (1988))), C5 (epitope within A1 residues 351-361) and T5 (epitope within the residues 701-740 (Fulcher, C.A., *et al.*, *J. Clin. Invest.* 76:117-124 (1985))) were kindly provided by Dr. Carol Fulcher (Scripps Clinic and  
20 Research Foundation, La Jolla, CA). The anti-A2 mAb 8860 was generously provided by Baxter/Hyland. Mab 413 (epitope within A2 domain residues 484-509 (Healey, *et al.*, *J. Biol. Chem.* 270:14505-14509 (1995))) was prepared as described previously (Saenko, E.L., *et al.*, *J. Biol. Chem.* 269:11601-11605 (1994)).

25 **Proteins.** LRP was isolated from human placenta as described (Ashcom, J.D., *et al.*, *J. Cell Biol.* 110:1041-1048 (1990)). Human RAP was expressed in bacteria and purified as described (Williams, S.E., *et al.*, *J. Biol. Chem.* 267:9035-9040 (1992)). FVIII was purified from therapeutic concentrates of

Method M, American Red Cross (Saenko, E.L., *et al.*, *J. Biol. Chem.* 271:27424-27431 (1996)). HCh and LCh were prepared from fVIII as described previously (Saenko, E.L. and Scandella, D., *J. Biol. Chem.* 272, 18007-18014 (1995)). Purification of the A1/A3-C1-C2 dimer and A2 subunit was performed using ion exchange chromatography of thrombin activated fVIII on a Resource S column (Pharmacia) (Fay, P.T., *et al.*, *J. Biol. Chem.* 268, 17861-17866 (1993)). Residual A2 present in the A1/A3-C1-C2 preparation was removed by its passage over an immobilized mAb 8860 column equilibrated in 20 mM Tris, pH 7.4, 0.15 M NaCl, 5 mM CaCl<sub>2</sub>.

10 **Radiolabeling of fVIII and synthetic peptides.** Prior to iodination fVIII and A2 were dialyzed into 0.2 M sodium acetate, 5 mM calcium nitrate, pH 6.8 (iodination buffer). Five  $\mu$ g of fVIII in 30  $\mu$ l of iodination buffer were added to lactoperoxidase beads (Worthington Biochemical Corp.), 5  $\mu$ l of Na<sup>125</sup>I (100 mCi/ml, Amersham), and 5  $\mu$ l of 0.03% H<sub>2</sub>O<sub>2</sub> (Mallincrodt) and incubated for 4 min. Free Na<sup>125</sup>I was removed by chromatography on a PD10 column (Pharmacia). The specific radioactivity of fVIII and A2 was 3.5-5  $\mu$ Ci/ $\mu$ g of protein. The activity of <sup>125</sup>I-fVIII determined in the one-stage clotting assay (3740 units/ $\mu$ g) was similar to that of unlabeled fVIII.

20 **Solid-phase binding assays.** Homologous and heterologous ligand displacement assays were performed as previously described (Williams, S.E., *et al.*, *J. Biol. Chem.* 267:9035-9040 (1992)). Microtiter wells were coated with purified LRP or BSA (3  $\mu$ g/ml) in 50 mM Tris, 0.15 M NaCl, pH 8.0, for 16 h and then blocked with 3 % BSA in TBS. Coated wells were incubated with <sup>125</sup>I-A2 or <sup>125</sup>I-fVIII in 20 mM Tris-buffered saline pH 7.4, containing 5 mM CaCl<sub>2</sub>, 0.05 % Tween-20 in the presence or absence of unlabeled competitors for 1 h at 37°C. The radioactivity bound to the wells was counted using a  $\gamma$ -counter (Pharmacia). Affinity constants were derived from homologous and heterologous displacement

data using the computer program LIGAND (Munson, PT and Rodbard, D. *Anal. Biochem.* 107:220-239 (1980)).

Cell-mediated ligand internalization and degradation assays. A normal mouse embryonic fibroblast line (MEF) and a mouse embryonic fibroblast cell line that is genetically deficient in LRP biosynthesis (PEA 13) were obtained from Dr. Joachim Herz (University of Texas Southwestern Medical Center, Dallas, TX) and maintained as described (Willnow, T.E. and Herz, J., *J. Cell Sci.* 107:719-726 (1994)). Cells were seeded at  $1 \times 10^5$  cells/well and allowed to grow for 24 h at 37°C, 5% CO<sub>2</sub>. Cellular internalization and degradation assays were conducted as described previously (Kounnas, M.Z., *et al.*, *J. Biol. Chem.* 270:9307-9312 (1995)). Internalization and degradation of the <sup>125</sup>I-labeled fVIII and A2 was measured after incubation for indicated time intervals at 37°C in 0.5 ml of Dulbecco's modified medium (Gibco BRL) containing 2% BSA. Internalization was defined as radioactivity that is resistant to release from cells by trypsin (50 µg/ml) and proteinase K (50 µg/ml) (Sigma) in a buffer containing 5 mM EDTA. This treatment was previously shown to release radioligand bound to cell surface (Kounnas, M.Z., *et al.*, *J. Biol. Chem.* 270:9307-9312 (1995)) and therefore the ligand remained associated with cells after this treatment was considered as internalized. Degradation was defined as radioactivity in the medium that is soluble in 10% trichloroacetic acid. The value of degradation was corrected for non-cellular mediated degradation by subtracting the amount of degradation products generated in parallel wells lacking cells.

25 **Clearance of  $^{125}\text{I}$ -A2 domain and  $^{125}\text{I}$ -fVIII/vWF complex from mouse plasma.**  
The complex of  $^{125}\text{I}$ -labeled fVIII with vWF in the presence or absence of RAP (in a total volume 250  $\mu\text{l}$ ) was injected in a tail vein of BALB/C mice over a period of approximately 20 seconds. At selected time intervals following injection (1, 3, 6, and 18 min), blood (50  $\mu\text{l}$ ) was withdrawn from the orbital plexus into 10  $\mu\text{l}$  of 100 mM EDTA, and the radioactivity of the aliquot was determined. The

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percentage of ligand remaining in circulation was calculated considering radioactivity of the aliquot taken at 1 min after injection as 100%. The clearance of each preparation was examined in two mice and the results were averaged. At the end of experiment, animals were sacrificed, liver lobules and kidneys were excised and weighed, followed by measuring the radioactivity in these tissues.

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### Results

**Factor VIII binds to LRP and its binding is prevented by RAP.** The ability of fVIII to bind to LRP *in vitro* was examined in homologous displacement binding assay. In the assay, binding of  $^{125}\text{I}$ -fVIII (1 nM) to purified LRP, but not to BSA-coated wells, was competed (> 90%) by excess of unlabeled fVIII (Fig. 5A). The quantitative data regarding fVIII interaction with LRP were derived from the homologous displacement of  $^{125}\text{I}$ -fVIII by unlabeled fVIII, which was adequately described by a model containing a single class of fVIII binding sites with  $K_d$  of 116 nM. To elucidate whether fVIII in a complex with vWF is also able to bind to LRP, we tested the effect of vWF on  $^{125}\text{I}$ -fVIII binding to immobilized LRP. In this experiment,  $^{125}\text{I}$ -fVIII was preincubated with vWF for 30 min at 37°C to allow complex formation prior to its addition to LRP coated wells. As shown in Fig. 5A,  $^{125}\text{I}$ -fVIII binding to LRP was not inhibited by vWF up to the concentration of 1000 nM, which is 20-fold higher than its concentration in plasma (50 mM (Vlot, A.J., *et al.*, *Blood* 85:3150-3157 (1995))). This indicates that the complex formation with vWF does not affect fVIII ability to bind to LRP.

RAP, the antagonist of LRP-ligand binding, completely inhibited the binding of  $^{125}\text{I}$ -fVIII to LRP-coated wells with  $K_i$  of 2.5 nM (Fig. 5B), a value similar to the previously determined affinity (4 nM) of RAP for LRP (Strickland, D.K., *et al.*, *J. Biol. Chem.* 265:17401-17404 (1990)). Together, these results demonstrate specific fVIII binding to LRP.

The amino acid residues 484-509 within the fVIII A2 domain are responsible for fVIII binding to purified LRP. In order to localize fVIII region(s) involved in interaction with LRP, binding between  $^{125}\text{I}$ -fVIII and immobilized LRP was competed by unlabeled fVIII fragments. As shown in Fig. 6, HCh and A2 domain of fVIII, but not LCh (AR-A3-Cl-C2) or A1/A3-C1-C2 dimer, displaced  $^{125}\text{I}$ -fVIII from LRP in the heterologous ligand displacement assay. The  $K_i$  values determined for the HCh and A2 were similar, 120 nM and 132 nM, respectively. The similarity of the above  $K_d$  value for fVIII binding to LRP and the  $K_i$  value for inhibition of this binding by isolated A2 subunit indicates that A2 domain of HCh is responsible for fVIII binding to LRP.

To localize the region of the A2 domain responsible for the interaction with LRP, we tested the effect of anti-A2 monoclonal antibodies with known epitopes on fVIII/LRP binding. Fig. 7A shows that mAb 413 (epitope within the A2 domain residues 484-509 (Healey, J.F., *et al.*, *J. Biol. Chem.* 270:14505-14509 (1995))) but not mAb T5 (epitope within the A2 domain residues 701-740 (35)) is able to block fVIII/LRP interaction. The concentration of mAb 413 required for 50% inhibition of  $^{125}\text{I}$ -fVIII/LRP binding was 2.5 nM. The low molar excess (2.5-fold) of mAb 413 over fVIII required for 50% inhibition of fVIII/LRP binding is consistent with a previously reported high affinity of mAb 413 for fVIII (Lollar, P., *et al.*, *J. Clin. Invest.* 93:2497-2504 (1994)). In a control experiment, mAbs C5 (epitope within A1 residues 351-361) and C4 (epitope within LCh residues 1670-1684 (Foster, P.A., *et al.*, *J. Biol. Chem.* 263:5230-5234 (1988))) did not have any effect on fVIII binding to LRP (data not shown), which is consistent with the lack of participation of A1 and LCh in fVIII binding to LRP.

25 Since it was previously demonstrated that mAb 413 recognizes synthetic peptide with a human fVIII sequence 484-509 (Healey, J.F., *et al.*, *J. Biol. Chem.* 270:14505-14509 (1995)), we tested if the region of the A2 domain encompassed by peptide 484-509 is involved in binding to LRP. As seen from Fig. 7B, the synthetic peptide 484-509, but not the control A2 peptide 432-456, inhibited fVIII binding to LRP in a dose-dependent fashion, indicating that the region 484-509

of the A2 domain contains critical residues for fVIII binding to LRP. In a control experiment, no binding of  $^{125}\text{I}$ -fVIII to BSA-coated wells was observed in the presence of peptide 484-509 (Fig. 7B).

Internalization and degradation of  $^{125}\text{I}$ -fVIII complex with vWF by cultured fibroblasts is mediated by LRP. Since the data presented above demonstrated specific interaction between fVIII and LRP, and vWF does not interfere with this interaction, we hypothesized that LRP may be also capable of mediating the cellular internalization of  $^{125}\text{I}$ -fVIII from its complex with vWF. To examine this hypothesis, cellular uptake and degradation experiments were conducted in mouse embryonal fibroblasts (MEF) which express LRP and in PEA 13 fibroblasts that are genetically deficient in LRP (Willnow, T.E. and Herz, J. *J. Cell Sci.* 107:719-726 (1994)). The  $^{125}\text{I}$ -fVIII/vWF complex was prepared by 30 min (37°C) incubation of  $^{125}\text{I}$ -fVIII with vWF at their plasma concentrations of 1 nM and 50 nM, respectively. As shown in Figs. 8A and B, MEF cells, but not PEA 13 cells lacking LRP, were capable of internalizing and degrading of  $^{125}\text{I}$ -fVIII in the presence of vWF. Further, internalization and degradation of  $^{125}\text{I}$ -fVIII by MEF but not by PEA 13 fibroblasts was inhibited by RAP, an antagonist of ligand binding to LRP. The ability of RAP to block the uptake and degradation of  $^{125}\text{I}$ -fVIII/vWF in MEF cells and inability of PEA 13 cells to efficiently mediate uptake and degradation indicates that LRP is the mediator of  $^{125}\text{I}$ -fVIII/vWF catabolism. To further characterize the degradation pathway of fVIII in the MEF cells, we tested the effect of chloroquine (an agent that blocks lysosomal degradation) on  $^{125}\text{I}$ -fVIII degradation. As seen from Fig. 8B, the degradation of  $^{125}\text{I}$ -fVIII is completely inhibited by chloroquine.

25 To elucidate if fVIII internalization in the absence of vWF is also mediated by LRP, we measured the internalization and degradation of isolated  $^{125}\text{I}$ -fVIII (Fig. 9). As seen from Figs. 9A and B, both internalization and degradation of isolated  $^{125}\text{I}$ -fVIII by MEF fibroblasts is approximately 2-fold higher than that in the presence of vWF. RAP inhibited internalization and degradation of  $^{125}\text{I}$ -fVIII

to a lesser degree than those of  $^{125}\text{I}$ -fVIII/vWF complex and, in addition, LRP-deficient PEA 13 fibroblasts were able to internalize and degrade isolated  $^{125}\text{I}$ -fVIII. This indicates that LRP-mediated pathway is not the sole mechanism of fVIII internalization and degradation in the absence of vWF.

5 To determine whether vWF bound to fVIII is also internalized and degraded by MEF cells, internalization and degradation of  $^{125}\text{I}$ -labeled vWF complexed with fVIII was measured. As shown in Figs. 9A and B, the amounts of internalized and degraded  $^{125}\text{I}$ -vWF by both MEF and PEA 13 cells were less than 5 % of the corresponding amounts of  $^{125}\text{I}$ -fVIII catabolized from its complex with vWF under the same experimental conditions. This indicates that vWF does not follow fVIII in the LRP-mediated pathway and possibly dissociates from fVIII 10 at early stage of endocytosis, prior to entry of the complex into endosomal compartments.

15 **The A2 subunit of fVIII inhibits endocytosis and degradation of  $^{125}\text{I}$ -fVIII/vWF by MEF cells.** Since we have demonstrated above that the A2 subunit of fVIII prevents an *in vitro* interaction between LRP and fVIII, we examined if A2 can also inhibit LRP-mediated internalization and degradation of fVIII/vWF complex by MEF cells. Figs. 10A and B demonstrate that 1000-fold excess of the 20 A2 subunit over  $^{125}\text{I}$ -fVIII/vWF complex effectively inhibit internalization (by >70% after 4 hours) and degradation (by >60% after 4 hours) of this complex. In contrast, A1/A3-Cl-C2 heterodimer, which did not inhibit fVIII interaction with purified LRP in the above experiments, did not have any effect on  $^{125}\text{I}$ -fVIII endocytosis and degradation by MEF cells (Fig. 10).

25 To confirm that the inhibitory effect of the A2 subunit results from its direct competition with  $^{125}\text{I}$ -fVIII/vWF complex for LRP-mediated internalization and degradation, we tested whether MEF cells are able to internalize and degrade isolated A2 subunit. As shown in Figs. 11A and B,  $^{125}\text{I}$ -A2 is readily internalized and degraded by LRP-expressing MEF cells. Both the internalization and degradation of the  $^{125}\text{I}$ -labeled A2 were blocked in the presence of RAP. In

contrast, LRP-deficient PEA 13 cells were unable to internalize or degrade  $^{125}\text{I}$ -A2 (Fig. 11), confirming that catabolism of the A2 subunit is LRP-mediated.

5 To verify that LRP-mediated internalization and degradation of the A2 domain was not the unique feature of the MEF cells, we tested  $^{125}\text{I}$ -labeled A2 internalization and degradation by smooth muscle cells (SMC) and alveolar epithelial cells (T2), which also express LRP on their surfaces (Moestrup, S.K., *Cell Tissue Res.* 269:375-382 (1992)). As shown in Figs. 11C and D, RAP effectively inhibited both internalization of  $^{125}\text{I}$ -A2 by SMC and T2 (by 81 % and 10 64 %, respectively), and its degradation (by 78 % and 68 %), indicating that these processes were mediated by LRP.

Thus, the data shown in Figs. 10 and 11 demonstrate that LRP is capable of binding fVIII via its A2 domain and of mediating fVIII endocytosis leading to lysosomal degradation.

15 **Effect of RAP on the plasma clearance of  $^{125}\text{I}$ -fVIII and  $^{125}\text{I}$ -A2.** To determine whether LRP is capable of catabolizing the isolated fVIII A2 subunit and whole fVIII from its complex with vWF *in vivo*, the effect of RAP on the clearance rates of  $^{125}\text{I}$ -fVIII/vWF complex and  $^{125}\text{I}$ -A2 in mice was tested. As shown in Fig. 12A, RAP increased the half-life of both  $^{125}\text{I}$ -A2 and  $^{125}\text{I}$ -fVIII in mouse plasma by approximately 4 and 2.5-fold, respectively. In addition, in the absence of RAP, 20 most of radioactivity was found in the liver but not in kidney, consistent with LRP

25 presence in high abundance in hepatic tissues (Strickland, D.K., *et al.*, *FASEB J.* 9:890-898 (1995)). Thus, our data indicate that a RAP-sensitive hepatic receptor, LRP, plays a major role in the removal of fVIII and its A2 subunit from circulation.

***Discussion***

5           In the present study we demonstrated that LRP mediates the internalization and degradation of human fVIII in a model system using LRP-expressing cells and is responsible for fVIII clearance *in vivo*. This conclusion is based on several independent observations. First of all, we found that fVIII directly binds to purified LRP immobilized on microtiter wells, and that this binding is competed by RAP, an antagonist of ligands binding to LRP. Second, <sup>125</sup>I-fVIII is internalized from its complex with vWF by mouse fibroblasts expressing LRP (MEF cells), but not by mouse fibroblasts genetically deficient in LRP (PEA 13 cells). Third, we demonstrated that RAP effectively inhibited the cellular uptake and degradation of <sup>125</sup>I-fVIII from its complex with vWF by MEF cells and *in vivo* clearance of <sup>125</sup>I-fVIII from circulation in mice.

10           Our studies revealed that the A2 domain of fVIII is responsible for its interaction with LRP, since only A2 domain and HCh, which contains the A2 domain, were able to inhibit the interaction of <sup>125</sup>I-fVIII with LRP in a purified system. Thus, it was concluded that A2 is responsible for fVIII binding to LRP. Based on the observation that vWF did not inhibit fVIII binding to LRP, we proposed that LRP may internalize fVIII from its complex with vWF. Indeed, mouse embryonic fibroblasts (MEF) that express LRP, but not fibroblasts genetically deficient in LRP, were able to internalize and degrade <sup>125</sup>I-fVIII in the presence of vWF. These processes were competed by RAP and A2 subunit of fVIII, indicating that cellular internalization and degradation were mediated by interaction of the A2 domain of fVIII with LRP. The physiological relevance of the observations utilizing the LRP-expressing cell model system was supported by *in vivo* clearance studies of <sup>125</sup>I-fVIII/vWF complex in mice which demonstrated that RAP prolonged the half-life of <sup>125</sup>I-fVIII in circulation by 2.5-fold, indicating that a RAP-sensitive receptor, most likely LRP, is responsible for the clearance of fVIII from plasma.

5 Further localization of the region within the A2 domain responsible for its binding to purified LRP was initiated by the finding that monoclonal antibody with an epitope within A2 domain residues 484-509 completely inhibited fVIII interaction with LRP. Inhibition of fVIII/LRP binding by synthetic peptide with a human fVIII sequence 484-509 indicated that the region of the A2 domain is likely to be directly involved in fVIII binding to purified LRP.

10 The region 484-509 contains 6 positively charged residues, Lys at positions 493, 496 and 499 and Arg at positions 484, 489 and 490. Basic residues in lipoprotein lipase (Chappell, D.A., *et al.*, *J. Biol. Chem.* 268:14168-14175 (1993)), u-PA-PAI-1 complex (Rodenburg, K.W., *et al.*, *Biochem. J.* 329:55-63 (1998)), and  $\alpha_2$ -macroglobulin (Howard, G. C., *et al.*, *J. Biol. Chem.* 271:14105-14111 (1996)) were previously shown to be critical for electrostatic interaction with LRP. Alanine substitution of the basic amino acid residues in lipoprotein lipase (Williams, S.E., *et al.*, *J. Biol. Chem.* 269:8653-8658 (1994)), u-PA/PAI-I complex (Rodenburg, K.W., *et al.*, *Biochem. J.* 329:55-63 (1998)) and in the receptor binding fragment from  $\alpha_2$ -macroglobulin (Howard, G.C., *et al.*, *J. Biol. Chem.* 271:14105-14111 (1996)) lead to a considerable reduction of affinity for ligand binding to LRP and partial (Rodenburg, K.W., *et al.*, *Biochem. J.* 329:55-63 (1998)) or complete (Howard, G.C., *et al.*, *J. Biol. Chem.* 271:14105-14111 (1996)) inhibition of internalization and degradation of the mutants. Therefore, 15 Ala or other amino acid substitutions within the 484-509 region of the recombinant fVIII are useful for reduction of the rate of its LRP-mediated endocytosis and generation of the fVIII mutants with a longer life in the circulation.

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25 FVIII binds to purified LRP with affinity 116 nM, which is much lower than the concentration of fVIII/vWf complex in plasma (1 nM; Wion, K., *et al.*, *Nature* 317:726-730 (1985)). FVIII affinity for LRP is similar to that of the complexes of serine proteases with inhibitors such as ATIII/thrombin (Kounnas, M.Z., *et al.*, *J. Biol. Chem.* 271:6523-6529 (1996)), HCII/thrombin and  $\alpha_1$ -antitrypsin/trypsin (Kounnas, M.Z., *et al.*, *J. Biol. Chem.* 271:6523-6529 (1996)),

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which also bind to LRP with affinities 80-120 nM, and weaker than measured for other LRP ligands. It was shown (Kounnas, M.Z., *et al.*, *J. Biol. Chem.* 271:6523-6529 (1996)) that internalization and degradation of the above low affinity LRP ligands at their 1 nM concentration by MEF cells occur at a lower rate than that of the u-PA/PAI- I complex which binds to LRP with high affinity ( $K_d < 1$  nM). Therefore, relatively low affinity of fVIII for LRP is responsible for a slow rate of fVIII internalization and degradation by MEF cells, which is comparable to the rate of ATIII/thrombin, HCII/thrombin and  $\alpha$ 1-antitrypsin/trypsin degradation at 1 nM concentration of each ligand. The low affinity of fVIII for LRP may also be a necessary requirement for the relatively long fVIII half-life (12-14 h) in plasma of normal individuals (Over, J., *et al.*, *J. Clin. Invest.* 62:223-234 (1978)). Alternatively, the low fVIII affinity for LRP may be compensated by concentration of fVIII molecules on the membrane of LRP-expressing cells, for example, via interaction with cell-surface proteoglycans which have been shown to facilitate the uptake of a number of LRP ligands including lipoprotein lipase (Chappell, D.A., *et al.*, *J. Biol. Chem.* 268:14168-14175 (1993)), hepatic lipase (Kounnas, M.Z., *et al.*, *J. Biol. Chem.* 270:9307-9312 (1995)), and thrombospondin (Mikhailenko, I., *et al.*, *J. Biol. Chem.* 270:9543-9549 (1995); Mikhailenko, I., *et al.*, *J. Biol. Chem.* 272:6784-6791 (1997)).

We found that internalization and degradation of isolated fVIII by MEF cells was greater than the corresponding processes for fVIII bound to vWF. In addition, catabolism of the isolated fVIII by MEF cells was only partially inhibited by RAP, indicating that LRP-mediated endocytosis of fVIII is not the sole mechanism of fVIII clearance in the absence of vWF. Our data suggest that in the presence of vWF, which blocks C2 domain-mediated fVIII binding to phospholipid membranes (Saenko, E.L. and Scandella, D., *J. Biol. Chem.* 270:13826-13833 (1995)), fVIII binds only to LRP, whereas in the absence of vWF, fVIII binds both to LRP and to an unidentified cell membrane component. The latter binding may lead to fVIII internalization via RAP-independent

pathway, which may be mediated by unidentified receptor as it was previously proposed for hepatic lipase (Kounnas, M.Z., *et al.*, *J. Biol. Chem.* 270:9307-9312 (1995)). Since we found that  $^{125}\text{I}$ -vWF is not internalized by MEF cells, we propose the model for fVIII endocytosis where fVIII/vWF complex binds to LRP and then vWF dissociates from fVIII during the early stage of fVIII endocytosis, *i.e.* during formation of the coated pits. Since the half-life for the dissociation of fVIII/vWF complex is about 1 hour (Saenko, E.L. and Scandella, D., *J. Biol. Chem.* 272, 18007-18014 (1995)), vWF may delay LRP-mediated endocytosis of fVIII according to the proposed model.

Faster catabolism of fVIII in the absence of vWF is consistent with a demonstrated shorter half-life of fVIII in patients with severe von Willebrand disease (vWD) lacking plasma vWF than that in hemophilia A patients, who have normal levels of vWF (Morfini, M., *et al.*, *Thromb. Haemostas.* 70:270-272 (1993); Lethagen, S., *et al.*, *Ann. Hematol.* 65:253-259 (1992)). Moreover, the half-life of fVIII in vWD patients was prolonged by the presence of vWF in the infused fVIII preparation (Lethagen, S., *et al.*, *Ann. Hematol.* 65:253-259 (1992)). The above observations were previously explained by vWF-mediated stabilization of fVIII by binding to vWF (Wise, R.J., *et al.*, *J. Biol. Chem.* 266:21948-21955 (1991)) and via secondary vWF-mediated release of endogenous fVIII (Wise, R.J., *et al.*, *J. Biol. Chem.* 266:21948-21955 (1991); Kaufman, R.J., *Mol. Cell. Biol.* 9:1233-1242 (1989)). Our data suggest that in addition to the above effects, vWF may reduce the rate of fVIII clearance by preventing LRP-independent pathway and limiting fVIII clearance to LRP-mediated pathway.

The activity of the factor X activation complex (factor Xase), consisting of membrane-bound activated fVIIa and factor IXa, can be down regulated by inactivation of fVIIa. The latter occurs via proteolytic degradation of fVIII by activated protein C, factor Xa and factor IXa, and via spontaneous but reversible dissociation of the A2 subunit from fVIIa heterotrimer (Fay, P. J. and Smudzin, T. M., *J. Biol. Chem.* 267:13246-13250 (1992)). Dissociation of the fVIIa heterotrimer may be accelerated by LRP mediated internalization of the A2

domain, and therefore complement regulation of fVIIIa activity at the sites of coagulation. This hypothesis is supported by availability of LRP at these sites, since LRP is exposed on the surface of monocytes and macrophage (Moestrup, S.K., *et al.*, *Exp. Cell. Res.* 190:195-203 (1990); Moestrup, S.K., *et al.*, *Cell Tissue Res.* 269:375-382 (1992)) and upon vascular injury on fibroblasts and smooth muscle cells (Moestrup, S.K., *et al.*, *Cell Tissue Res.* 269:375-382 (1992)). In addition, it was recently shown that isolated A2 but not isolated A1 and A3-C1-C2 subunits of activated fVIII is able to accelerate factor IXa-catalyzed conversion of factor X by approximately 100-fold (Fay, P.J. and Koshibu, K., *Blood* 92:353a (abstract) (1998)). Even though acceleration of the factor X activation by A2 is only 1 % of that in the presence of heterotrimeric activated fVIII (A1/A2/A3-C1-C2) (Fay, P.J. and Koshibu, K., *Blood* 92:353a (abstract) (1998)), it is possible that LRP-mediated removal of the A2, dissociated from fVIIIa bound to a phospholipid membrane at the site of coagulation, is important to prevent activation of factor X not in the place of the coagulation event.

In summary, the current study demonstrates that LRP can bind fVIII/vWF complex and mediate uptake of fVIII from it. *In vivo* clearance studies underscored the likelihood that LRP indeed functions to remove LRP from plasma.

*Example 3*

**Experiments on the development of recombinant fVIII molecule with extended lifetime in circulation.** Since recombinant fVIII products are widely used for fVIII replacement therapy in hemophiliacs who have decreased or nonfunctional fVIII, generation of mutant(s) with a prolonged lifetime is a promising approach to increase the efficacy and reduce the cost of fVIII infusion therapy. A 39 kDa receptor associated protein (RAP) binds reversibly to LRP and inhibits the binding of other ligands and therefore serves as a useful tool for

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testing whether LRP is involved in endocytosis of a given ligand. We found that fVIII binding to LRP is inhibited by RAP, confirming the specificity of this interaction. Since von Willebrand factor (vWf), bound to fVIII in the circulation, does not inhibit fVIII binding to purified LRP, we proposed that removal of the fVIII/vWf complex from the circulation may also be LRP-mediated. This role of LRP was supported by our finding that the lifetime of human  $^{125}\text{I}$ -fVIII/vWf complex in mice was 2.5-times prolonged in the presence of RAP.

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Based on our finding that fVIII amino acids 484-509 were important for fVIII binding to LRP, these amino acids are also important for LRP-mediated endocytosis. To identify the key fVIII amino acids required for endocytosis, single residues 484-509 are mutated to Ala in the B- domain deleted fVIII (B(-) fVIII). Since the basic residues are commonly involved in ligand binding to LRP, six basic residues within 484-509 (3 Lys and 3 Arg) are mutated. U.S. Patent No. 55,859,204 discloses the substitution to Ala of three of these residues (Arg<sup>484</sup>, Lys<sup>493</sup> and Arg<sup>490</sup>); however the other 3 residues – Arg<sup>490</sup>, Lys<sup>496</sup> and Lys<sup>499</sup> – were not substituted. Thus, these residues, individually and in combination, are mutated to Ala. In particular, each of three Arg and each of three Lys are mutated by pairs (this implies preparation of 9 additional fVIII Ala double-mutants).

20

25

It is then determined whether endocytosis of the vWf complexes with B(-) fVIII mutant(s) by LRP-expressing cells is reduced compared to that of wild-type B (-) fVIII/vWf. Some mutations result in a decreased rate of internalization and a longer *in vivo* half-life of the complex of the B- fVIII mutant with vWf in plasma of mice compared to that of wild type B- fVIII/vWf complex. The data of the *in vivo* experiments performed in normal and fVIII-deficient mice is mathematically analyzed using biphasic time-course clearance model and equations approximating interspecies scaling which allow to predict fVIII half-life in humans (*Toxicology and Applied Pharmacology* 136:75-78 (1996)).

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Clearance of mutant fVIII in vWf-deficient mice which lack fVIII in circulation (a mouse model for severe von Willebrand disease is described in *Proc. Natl. Acad. Sci. USA* 95:9524-9529 (1998)) is also analyzed. These

experiments are aimed at determining mutant fVIII's prolonged half-life in the absence of vWF. Factor VIII interaction with endothelial cells is also analyzed, since this interaction leads to fVIII internalization. In experiments using fluorescent microscopy techniques we observed uptake of fVIII by endothelial 5 cells. Since a fine equilibrium exists in circulation between fVIII bound to vWF and fVIII bound and internalized by endothelial cells, fVIII interaction with phospholipid endothelial cell membrane is an important factor influencing concentration of fVIII (and hence its half-life) in circulation following fVIII injection.

10 Therefore, individual amino acids within the previously localized fVIII phospholipid binding site (C2 domain region 2303-2332) which play a role in fVIII binding to vWF and to phospholipid are identified. We identify the amino acids playing a key role in fVIII binding to phospholipid, but not to vWF. The amino acids which participate in fVIII binding to vWF and to phospholipids are 15 selected based on the following observations. The homology search between the C2 domain of fVIII and the corresponding region of the discoidin and a family of homologous proteins, containing the so called DS domain, has revealed the fVIII C2 domain sequences involved in the formation of  $\beta$ -structures. In addition, it has been shown that the synthetic fVIII peptide 2310-2320 in which residues 2310 20 and 2320 are covalently linked to reproduce the corresponding loop structure within the C2 domain, competes for fVIII binding with vWF or phospholipid. Therefore, residues within the 2311-2319 region are mutated to Ala, and other amino acids. Since fV, a fVIII homolog, does not bind to vWF, we mutate only 25 five residues which are unique within the 2311-2319 region of fVIII. The mutants are tested for binding to vWF and phospholipid, which identifies the fVIII residues playing a key role in binding to these ligands.

30 Clearance of the fVIII mutants with reduced phospholipid binding was compared with that of wt-fVIII in normal and hemophilic mice to determine the contribution of the phospholipid-dependent fVIII clearance component to total fVIII clearance.

The mutations within the C2 domain region 2310-2320 prove to be effective for extension of fVIII lifetime in circulation, so we generate mutant fVIII in which both the C2 domain mutation(s) (positions 2310-2320) and mutation(s) within the A2 (positions 484-509) are combined.

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We test the designed extended lifetime fVIII for gene therapy purposes. The extended lifetime fVIII gene is inserted in a virus-based vector, and delivered into hemophilia A mice. The time course of the fVIII *in vivo* expression level is assessed as follows: the number of the gene copies per cell (hepatic), the gene transcription level, fVIII activity and the antigen level are determined. Since it was shown that high titer antibodies increase clearance of fVIII (*Br. J. Hematol.* 93:688-693 (1996)), we examine the immune response against the extended lifetime fVIII. We also compare its half-life in circulation in hemophilia A mice which formed antibodies against wild type fVIII.

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***What Is Claimed Is:***

1. A mutant factor VIII comprising an amino acid substitution at two or more positions in the A2 domain; wherein at least one of said amino acid substitutions is not at any of positions 484, 485, 487, 488, 489, 492, 493, 495, 501 or 508; wherein the mutant factor VIII has reduced receptor-dependent clearance; and wherein the mutant factor VIII has procoagulant activity.  
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2. The mutant factor VIII of claim 1, which lacks the B domain.
3. The mutant factor VIII of claim 2, comprising an amino acid substitution at two or more of positions 484 to 509.
- 10 4. The mutant factor VIII of claim 3, comprising an amino acid substitution at two or more of positions 490, 496 or 499.
5. The mutant factor VIII of claim 3, comprising an amino acid substitution at one or more of positions 490, 496 or 499; and at one or more of positions 484, 489 or 493.  
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6. The mutant factor VIII of claim 5, comprising an amino acid substitution at position 490; and at one or more of positions 484, 489 or 493.
7. The mutant factor VIII of claim 5, comprising an amino acid substitution at position 496; and at one or more of positions 484, 489 or 493.  
20
8. The mutant factor VIII of claim 5, comprising an amino acid substitution at position 499; and at one or more of positions 484, 489 or 493.
9. The mutant factor VIII of claim 2, comprising SEQ ID NO:5.

10. A pharmaceutically acceptable composition comprising the mutant factor VIII of claim 2.

11. A method of treating hemophilia which comprises administering to a patient in need thereof an effective amount of the mutant factor VIII of claim 2.

12. The method of claim 11, which further comprises administering an effective amount of receptor associated protein (RAP).

13. A polynucleotide encoding the mutant factor VIII of claim 2.

14. A method of treating hemophilia which comprises administering to a patient in need thereof an effective amount of the polynucleotide of claim 13.

15. The method of claim 14, which further comprises administering an effective amount of a polynucleotide encoding RAP.

16. A mutant factor VIII comprising an amino acid substitution at one or more positions in the A2 domain, which is not at any of positions 484, 485, 487, 488, 489, 492, 493, 495, 501 or 508; wherein the mutant factor VIII has reduced receptor-dependent clearance; and wherein the mutant factor VIII has procoagulant activity.

17. The mutant factor VIII of claim 16, which lacks the B domain.

18. The mutant factor VIII of claim 17, comprising an amino acid substitution at one or more of positions 484 to 509.

19. The mutant factor VIII of claim 18, comprising an amino acid substitution at one or more of positions 490, 496 or 499.

20. The mutant factor VIII of claim 19, comprising an amino acid substitution at position 490.

5 21. The mutant factor VIII of claim 19, comprising an amino acid substitution at position 496.

22. The mutant factor VIII of claim 19, comprising an amino acid substitution at position 499.

23. The mutant factor VIII of claim 17, comprising SEQ ID NO:5.

10 24. A pharmaceutically acceptable composition comprising the mutant factor VIII of claim 17.

25. A method of treating hemophilia which comprises administering to a patient in need thereof an effective amount of the mutant factor VIII of claim 17.

15 26. The method of claim 25, which further comprises administering an effective amount of RAP.

27. A polynucleotide encoding the mutant factor VIII of claim 17.

28. A method of treating hemophilia which comprises administering to a patient in need thereof an effective amount of the polynucleotide of claim 27.

29. The method of claim 28, which further comprises administering an effective amount of a polynucleotide encoding RAP.

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30. A mutant factor VIII comprising an amino acid substitution at one or more positions in the C2 domain; wherein the mutant factor VIII has reduced receptor-independent clearance; and wherein the mutant factor VIII has procoagulant activity.

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31. The mutant factor VIII of claim 30, which lacks the B domain.

32. The mutant factor VIII of claim 31, comprising an amino acid substitution at one or more of positions 2303 to 2332.

33. The mutant factor VIII of claim 32, comprising an amino acid substitution at one or more of positions 2311 to 2319.

34. The mutant factor VIII of claim 31, comprising SEQ ID NO:1.

35. A pharmaceutically acceptable composition comprising the mutant factor VIII of claim 31.

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36. A method of treating hemophilia which comprises administering to a patient in need thereof an effective amount of the mutant factor VIII of claim 31.

37. The method of claim 36, which further comprises administering an effective amount of RAP.

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38. A polynucleotide encoding the mutant factor VIII of claim 31.

39. A method of treating hemophilia which comprises administering to a patient in need thereof an effective amount of the polynucleotide of claim 38.

40. The method of claim 39, which further comprises administering an effective amount of a polynucleotide encoding RAP.

5 41. A mutant factor VIII comprising:

(i) an amino acid substitution at two or more positions in the A2 domain; wherein at least one of said amino acid substitutions is not at any of positions 484, 485, 487, 488, 489, 492, 493, 495, 501 or 508; and

10 (ii) an amino acid substitution at one or more positions in the C2 domain as numbered in SEQ ID NO:1;

wherein the mutant factor VIII has reduced clearance; and wherein the mutant factor VIII has procoagulant activity.

42. The mutant factor VIII of claim 41, which lacks the B domain.

43. The mutant factor VIII of claim 42, comprising SEQ ID NO:5.

15 44. A pharmaceutically acceptable composition comprising the mutant factor VIII of claim 42.

45. A method of treating hemophilia which comprises administering to a patient in need thereof an effective amount of the mutant factor VIII of claim 42.

20 46. The method of claim 45, which further comprises administering an effective amount of RAP.

47. A polynucleotide encoding the mutant factor VIII of claim 42.

48. A method of treating hemophilia which comprises administering to a patient in need thereof an effective amount of the polynucleotide of claim 47.

49. The method of claim 48, which further comprises administering an effective amount of a polynucleotide encoding RAP.

5 50. A mutant factor VIII comprising:

(i) an amino acid substitution at one or more positions in the A2 domain, which is not at any of positions 484, 485, 487, 488, 489, 492, 493, 495, 501 or 508; and

10 (ii) an amino acid substitution at one or more positions in the C2 domain as numbered in SEQ ID NO:1;

wherein the mutant factor VIII has reduced clearance; and wherein the mutant factor VIII has procoagulant activity.

51. The mutant factor VIII of claim 50, which lacks the B domain.

52. The mutant factor VIII of claim 51, comprising SEQ ID NO:5.

15 53. A pharmaceutically acceptable composition comprising the mutant factor VIII of claim 51.

54. A method of treating hemophilia which comprises administering to a patient in need thereof an effective amount of the mutant factor VIII of claim 51.

20 55. The method of claim 54, which further comprises administering an effective amount of RAP.

56. A polynucleotide encoding the mutant factor VIII of claim 51.

57. A method of treating hemophilia which comprises administering to a patient in need thereof an effective amount of the polynucleotide of claim 56.

58. The method of claim 57, which further comprises administering an effective amount of a polynucleotide encoding RAP.

5 59. A polypeptide selected from the group consisting of:

- (a) a polypeptide comprising a fragment of receptor-associated protein (RAP) which binds LRP;
- (b) a polypeptide comprising a mutant of RAP which binds LRP;
- 10 (c) a polypeptide comprising an analog of RAP which binds LRP;
- (d) a polypeptide comprising 20 contiguous amino acids of the sequence of SEQ ID NO:4, which binds LRP; and
- (e) a polypeptide comprising amino acids 203 to 319 of SEQ 15 ID NO:4.

60. A pharmaceutically acceptable composition comprising the polypeptide of claim 59.

61. A method of treating hemophilia which comprises administering to a patient in need thereof an effective amount of the polypeptide of claim 59.

20 62. The method of claim 61, which further comprises administering a mutant factor VIII having an amino acid substitution at one or more positions in the A2 domain.

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63. The method of claim 61, which further comprises administering a mutant factor VIII having an amino acid substitution at one or more positions in the C2 domain.

5 64. The method of claim 61, which further comprises administering a mutant factor VIII having an amino acid substitution at one or more positions in the A2 domain and an amino acid substitution at one or more positions in the C2 domain.

10 65. A method of increasing the half-life of factor VIII, selected from the group consisting of:

15 (a) a method which comprises substituting an amino acid at two or more positions in the A2 domain; wherein at least one of said amino acid substitutions is not at any of positions 484, 485, 487, 488, 489, 492, 493, 495, 501 or 508; wherein the resulting factor VIII has reduced receptor-dependent clearance; and wherein the resulting factor VIII has procoagulant activity;

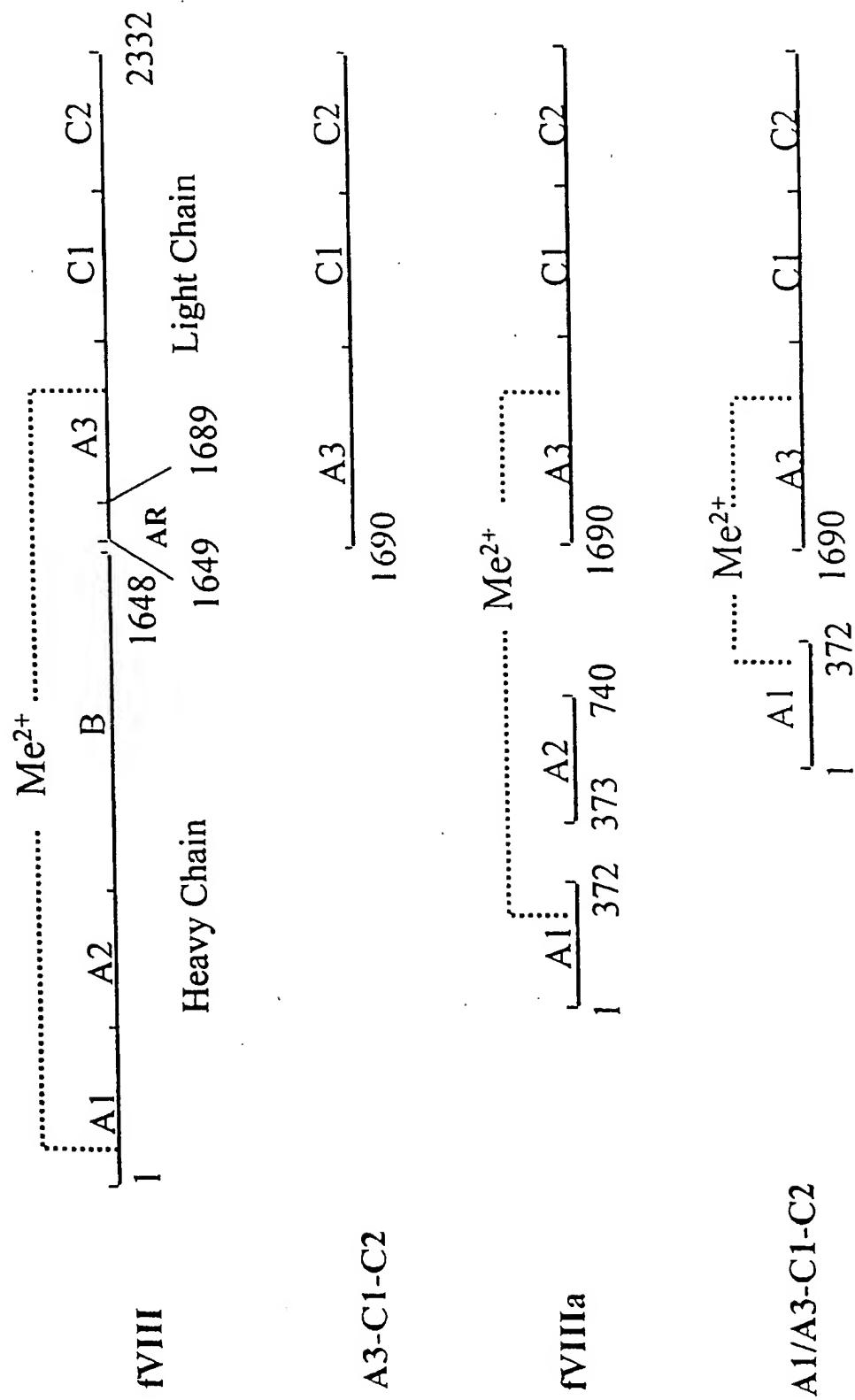
20 (b) method which comprises substituting an amino acid at one or more positions in the A2 domain, which is not at any of positions 484, 485, 487, 488, 489, 492, 493, 495, 501 or 508; wherein the resulting factor VIII has reduced receptor-dependent clearance; and wherein the resulting factor VIII has procoagulant activity;

25 (c) a method which comprises substituting an amino acid at one or more positions in the C2 domain; wherein the resulting factor VIII has reduced receptor-independent clearance; and wherein the resulting factor VIII has procoagulant activity;

(d) a method which comprises administering to a patient in need thereof an effective amount of a fragment of RAP, wherein said fragment binds LRP; and

25 (e) a method comprising two or more of methods (a), (b), (c) or (d).

FIG. 1



## FIG. 2A

ATRRYYLGAVELSWDYMQSSDLGELP

VDARFPPRVPKSFPFNTSVVYKKTLFVEFTDHLFNIAKPRPPWMGLLGPTIQAEVYDT

VVITLKNMASHPVSLHAVGVSYWKASEGAEYDDQTSQREKEDDKVFPAGSHTYVWQVL

KENGPMA SDPLCLTYSYLSHVDLVKDLNSGLIGALLVCREGSLAKEKTQTLHKFILLF

AVFDEGKSWHSETKNSLMQDRDAASARAWPKMHTVNGYVNRSLPGLIGCHRKSVYWHV

IGMGTTPEVHSIFLEGHTFLVRNHRQASLEISPITFLTAQTLLMDLGQFLLFCHISSH

QHDGMEAYVKVDSCPEEPQLRMKNNEEAEDYDDDLTDSEMDVVRFDDDNPSFIQIRS

VAKKHPKTWVHYIAAEEEDWDYAPLVLAPDDRSYKSOYLNNGPORIGRKYKKVRFMAYTDETFKTREAIOHESGILGPLLYGEVGDTLLIFKNOASRPYNIYPHGITDVRPLYSRA2 Domain

\*\*\*\*\*

LRP

RLPKGVKHLKDFPILPGEIFKYKWTVTVEDGPTKSDPRCLTRYSSFVNMERDLASGL

\*\*\*\*\*

Binding Region

IGPLLICYKESVDORGNOIMSDKRNVILFSVFDENRSWYLTENIORFLPNPAGVOLEDPEFOASNIMHSINGYVFDSSLQLSVCLHEVAYWYILSIGAQTDFLSVFFSGYTFKHKMVYEDTLTLPFSGETVFMSENPGWLILGCHNSDFRNRGMTALLKVSSCDKNTGDYYEDSYEDISAYLLSKNNAIEPREITRTTLQSDQEEIDYDDTISVEMKKEDFDIYDEDENQSPRSFQKKTRHYFIAAVERLWDYGMSSSPHVRNRAQSGSVPQFKVVFQEFTDGSFTQ

## FIG. 2B

PLYRGELNEHLGLLGPYIRAEVEDNIMVTFRNQASRPYSFYSSLISYEEDQRQGAEPR

KNFVKPNETKTYFWKVQHHMAPTKDEFDCKAWAYFSDVDLEKDVHSGLIGPLLVCHTN

TLNPAHGRQTVQEFALFFTIFDETWSYFTENMERNCRAPCNIQMEDPTFKENYRFH

AINGYIMDTLPGLVMAQDQRIRWYLLSMGSNEIHSIHFSGHVFTVRKKEEYKMALYN

LYPGVFETVEMLPSKAGIWRVECLIGEHLHAGMSTLFLVYSNKCQTPLGMASGHIRDF

QITASGQYQQWAPKLARLHYSGSINAWSKTEPFSWIKV DLLAPMIIHGIKTQGARQKF

SSLYISQFIIMYSLDGKKWQTYRGNSTGTLMVFFGNVDSSGIKHNI FN PPIARYIRL

HPTHYSIRSTLRMELMGCDLNCSMPLGMESKAISDAQITASSYFTNMFATWSPSKAR

LHLQGRSNAWRPQVNNPKEWLQVDFQKTMKVTGVTTQGVKSLLTSMYVKEFLISSQD

GHQWTLFFQNGKVKVFQGNQDSFTPVVNSLDPLLTRYLRIHPQSWVHQIALRMEVLG

CEAQDLY

## FIG. 3A

1 MQIELSTCFF LCLLRFCFSA TRYYLGAVE LSWDYMQSDL GELPVNDARFP PRVPKSFPFN  
61 TSVVYKKTLF VEFTDHLFNI AKPRPPWMGL LGPTIQAEVY DTVVITLKNM ASHPVSLHAV  
121 GVSYWKASEG AEYDDQTSQR EKEDDKVFPG GSHTYVWQVL KENGPMASDP LCLTYSYLSH  
181 VDLVKDLNSG LIGALLVCRE GSLAKEKTQT LHKFILLFAV FDEGKSWHSE TKNSLMQDRD  
241 AASARAWPKM HTVNGYVNRS LPGLIGCHRK SVYWHVIGMG TTPEVHSIFL EGHTFLVRNH  
301 RQASLEISPI TFLTAQTLLM DLGQFLLFCH ISSHQHDGME AYVKVDSCPE EPQLRMKNNE  
361 EAEDYDDDLT DSEMDVVRFD DDNSPSFIQI RSVAKKHPKT WVHYIAAEEE DWDYAPLVLA  
421 PDDRSYKSQY LNNGPQRIGR KYKKVRFMAY TDETFKTREA IQHESGILGP LLYGEVGDTL  
481 LIIFKNQASR PYNIYPHGIT DVRPLYSRRL PKGVKHLKDF PILPGEIFKY KWTVTVEDGP  
541 TKSDPRCLTR YYSSFVNMER DLASGLIGPL LICYKESVDO RGNQIMSDKR NVILFSVFDE  
601 NRSWYLTE NI QRFLPNPAGV QLEDPEFQAS NIMHSINGYV FDSLQLSVCL HEVAYWYIIS  
661 IGAQTDFLSV FFSGYTFKHK MVYEDTLLT PFSGETVFMS MENPGLWIIG CHNSDFRNNG  
721 MTALLKVSSC DKNTGDYYED SYEDISAYLL SKNNAIEPRS FSQNSRHRST RQKQFNATTI  
781 PENDIEKTDP WFAHRTMPMK IQNVSSSDLL MLLRQSPTPH GLSLSDLQEA KYETFSDDPS  
841 PGAIDSNNSL SEMTHFRPQL HHSGDMVFTP ESGLQLRLNE KLGTTAATEL KKLDFKVSST  
901 SNNLISTIPS DNLAAGTDNT SSLGPPSMPV HYDSQLDTTL FGKKSSPLTE SGGPLSLSEE  
961 NNDSKLLESG LMNSQESSWG KNVSSTESGR LFKGKRAHGP ALLTKDNALF KVSISLLKTN  
1021 KTSNNSATNR KTHIDGPSLL IENSPSVWQN ILESDETEFKK VTPLIHDRML MDKNATALRL  
1081 NHMSNKTSS KNMEMVQQKK EGPIPPDAQN PDMSFFKMLF LPESARWIQR THGKNSLNSG  
1141 QGPSPKQLVS LGPEKSVEGQ NFLSEKNKVV VGKGEFTKDV GLKEMVFPSS RNLFLTNLDN  
1201 LHENNTHNQE KKIQEEIEKK ETLIQENVVL PQIHTVTGTK NFMKNLFLLS TRQNEGSDY  
1261 GAYAPVILQDF RSLNDSTNRT KKHTAHFSKK GEEENLEGLG NQTKQIVEKY ACTTRISPNT  
1321 SQQNFTQRS KRALKQFRLP LEETELEKRI IVDDTSTQWS KNMKHLTPST LTQIDYNEKE  
1381 KGAITQSPLS DCLTRSHSIP QANRSPLPIA KVSSFPSIRP IYLTRVLFQD NSSHLPAASY  
1441 RKKDSGVQES SHFLQGAKKN NLSLAILTLE MTGDQREVGS LGTSATNSVT YKKVENTVLP  
1501 KPDLPKTSRK VELLPKVHIY QKDLFPTETS NGSPGHLDLV EGSSLQGTEG AIKWNEANRP  
1561 GKVPLRVAT ESSAKTPSKL LDPLAWDNHY GTQIPKEEWK SQEKSPEKTA FKKKDTILSL  
1621 NACESNHAIA AINEGQNKP EIEVTWAKQGR TERLCSQNPP VLKRHQREIT RTTLQSDQEE

## FIG. 3B

1681 IDYDDTISVE MKKEDFDIYD EDENQSPRSF QKKTRHYFIA AVERLWDYGM SSSPHVLRNR  
1741 AQSGSVPQFK KVVFQEFTDG SFTQPLYRGE LNEHLGLGP YIRAEVEDNI MVTFRNQASR  
1801 PYSFYSSLIS YEEDQRQGAE PRKNFVKPNE TKTYFWKVQH HMAPTKDEFD CKAWAYFSDV  
1861 DLEKDVHSGL IGPLLVCHTN TLNPAHGRQV TVQEFAFFT 1FDETWSWYF TENMERNCRA  
1921 PCNIQMEDPT FKENYRFHAI NGYIMDTLPG LVMAQDQRIR WYLLSMGSNE NIHSIHFSGH  
1981 VFTVRKKEEY KMALYNLYPG VFETVEMLPS KAGIWRVECL IGEHLHAGMS TLFLVYSNKC  
2041 QTPLGMASGH IRDFQITASG QYGQWAPKLA RLHYSGSINA WSTKEPFSWI KVDLLAPMII  
2101 HGIKTQGARQ KFSSLYISQF IIMYSLDGKK WQTYRGNSTG TLMVFFGNVD SSGIKHNIFN  
2161 PPIIARYIRL HPTHYSIRST LRMELMGCDL NSCSMPLGME SKAISDAQIT ASSYFTNMFA  
2221 TWSPSKARLH LQGRSNAWRP QVNNPKEWLQ VDFQKTMKVT GVTTQGVKSL LTSMYVKEFL  
2281 ISSSQDGHQW TLFFQNGKVK VFQGNQDSFT PVVNSLDPPL LTRYLRIHPQ SWVHQIALRM  
2341 EVLGCEAQDL Y

## FIG. 4

1 MAPRRVRSFL RGLPALLLL LFLGPWPAAS HGGKYSREKN QPKPSPKRES GEEFRMEKLN  
Signal Sequence

61 QLWEKAQRLH LPPVRLAELH ADLKIQERDE LAWKKLKLDG LDEDGEKEAR LIRNLNVILA

121 KYGLDGKKDA RQVTSNSLSC TQEDGLDDPR LEKLWHKAKT SGKFSGEELD KLWREFLHHK

181 EKVHEYNVLL ETLSRTEEIH ENVISPSDLS DIKGSVLHSR HTELKEKLRS INQGLDRLRR  
\*\*\*\*\*

241 VSHQGYSTEAE FEEEPRVIDL WDLAQSANLT DKELEAFREE LKHFEAKIEK HNHYQKQLEI  
\*\*\*\*\*  
LDL Binding Region

301 AHEKLRHAES VGDGERVSRS REKHALLEGR TKELGYTVKK HLQDLSGRIS RARHNEI  
\*\*\*\*\*

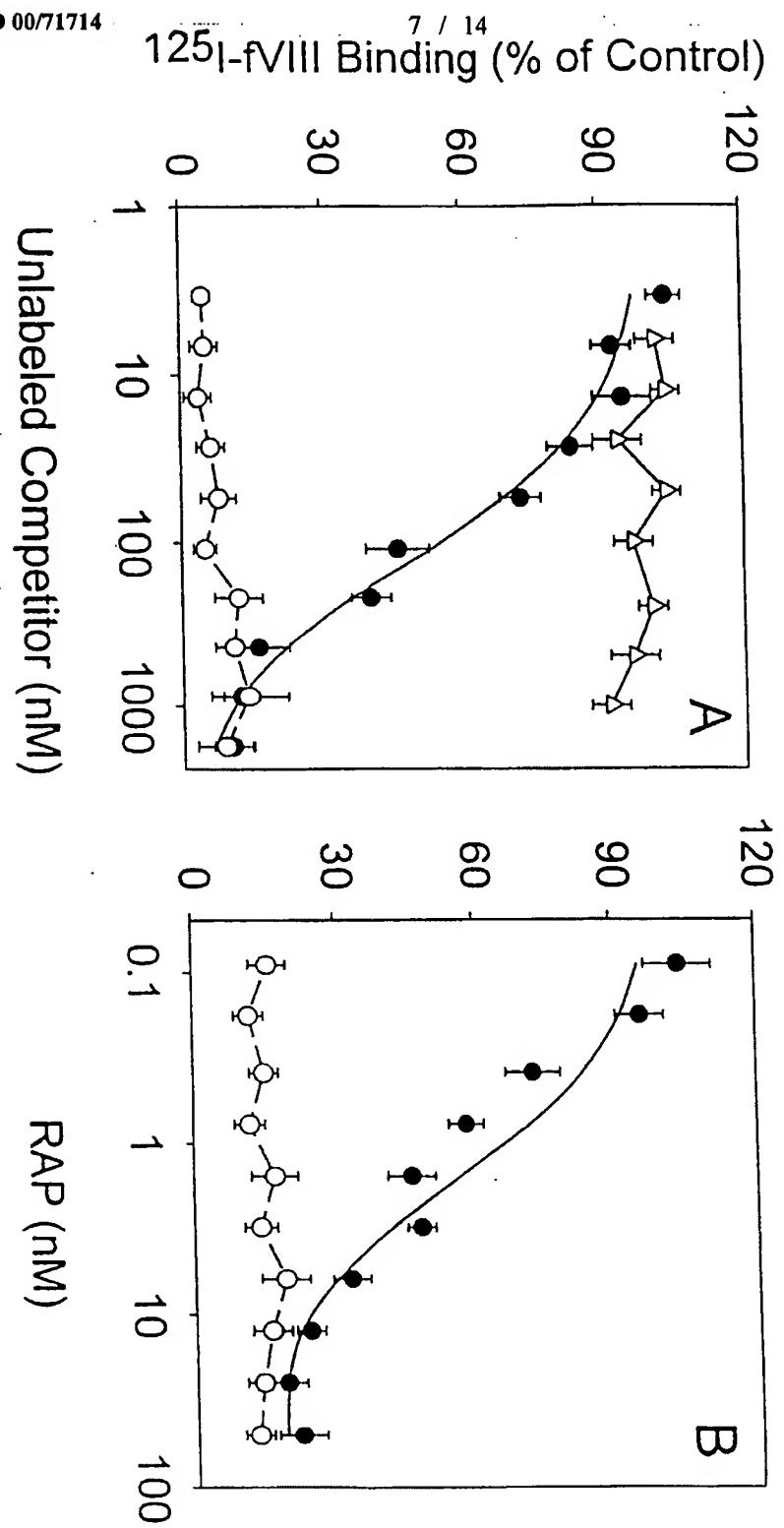


FIG. 5

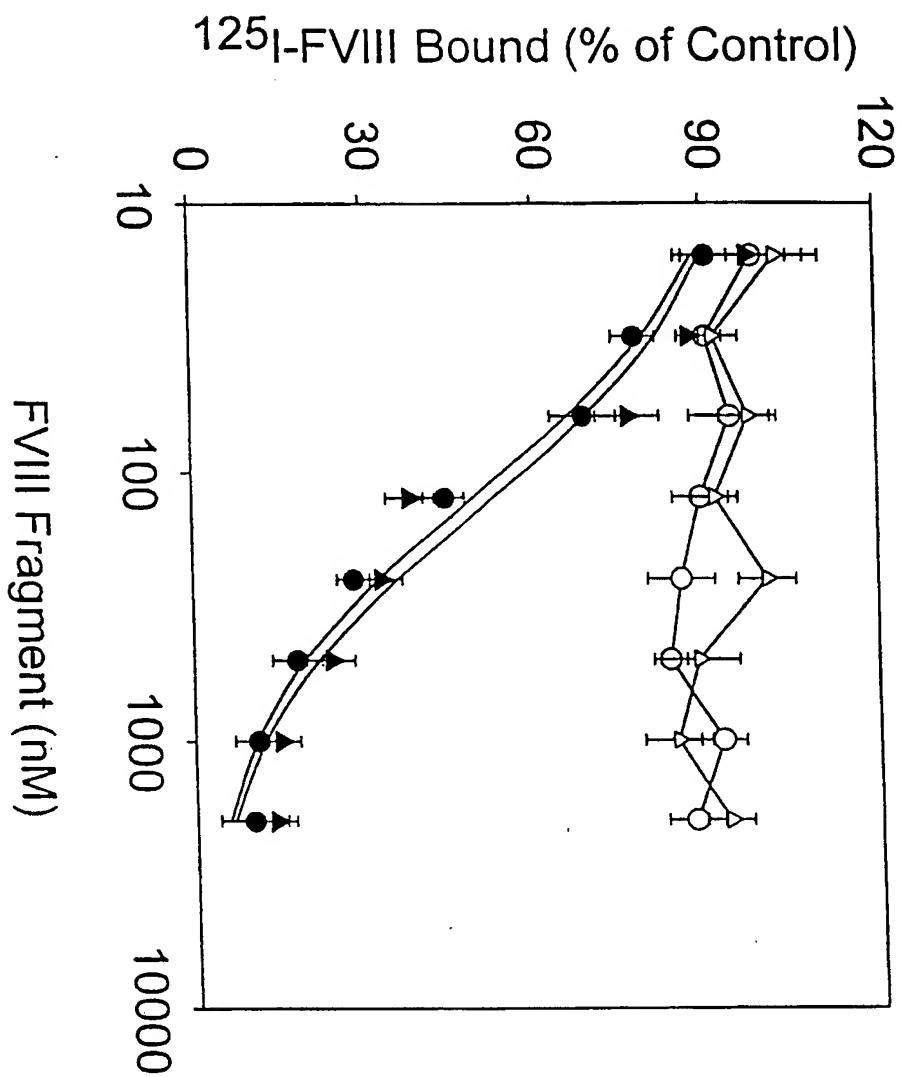


FIG. 6

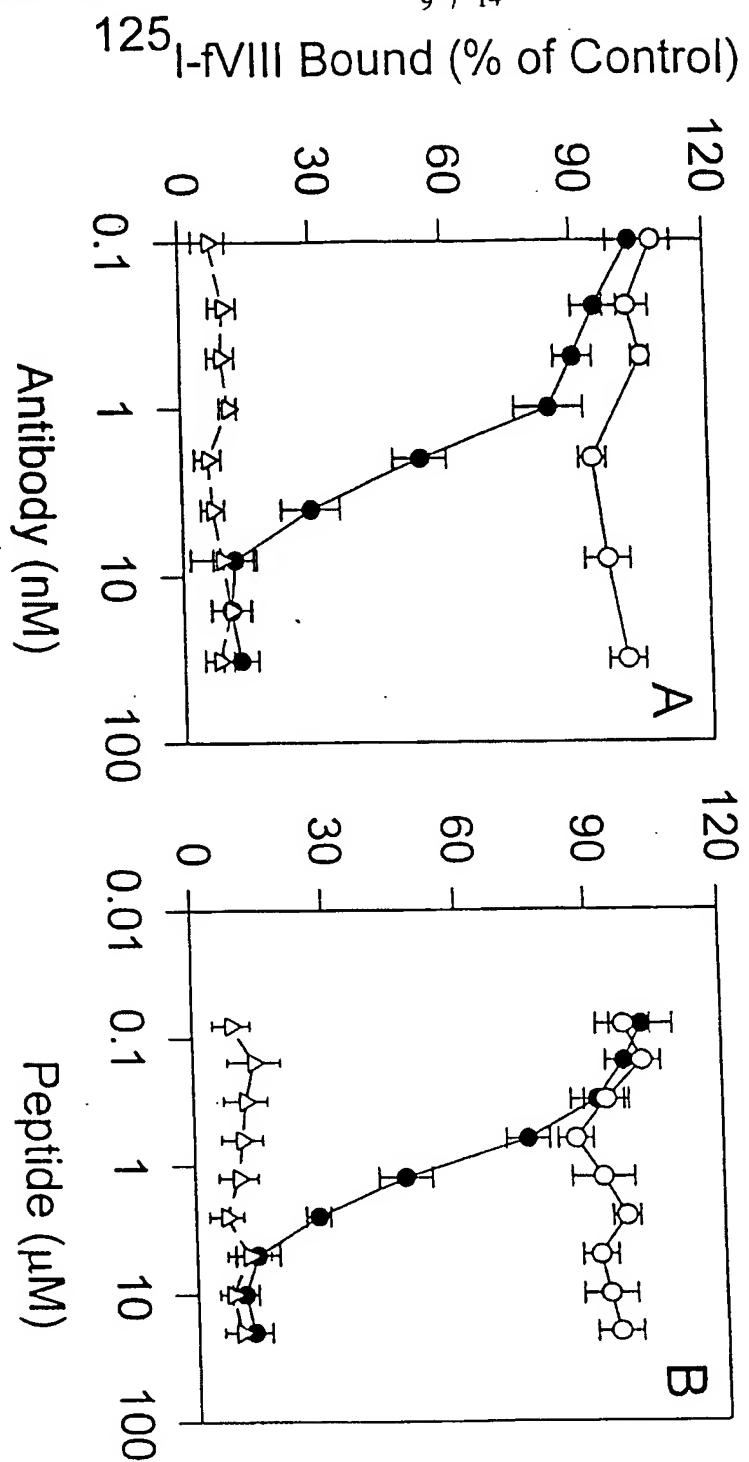


FIG. 7

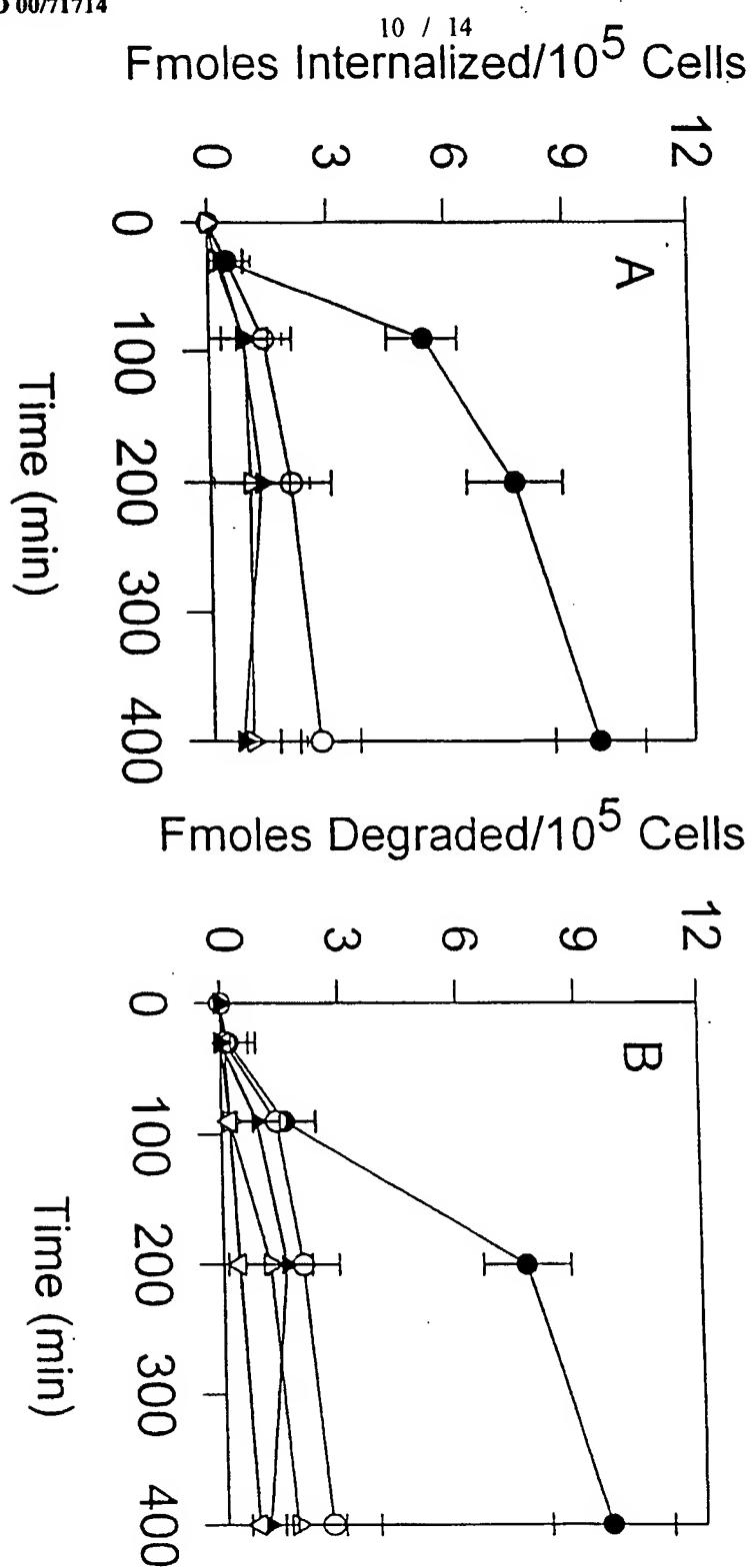


FIG. 8

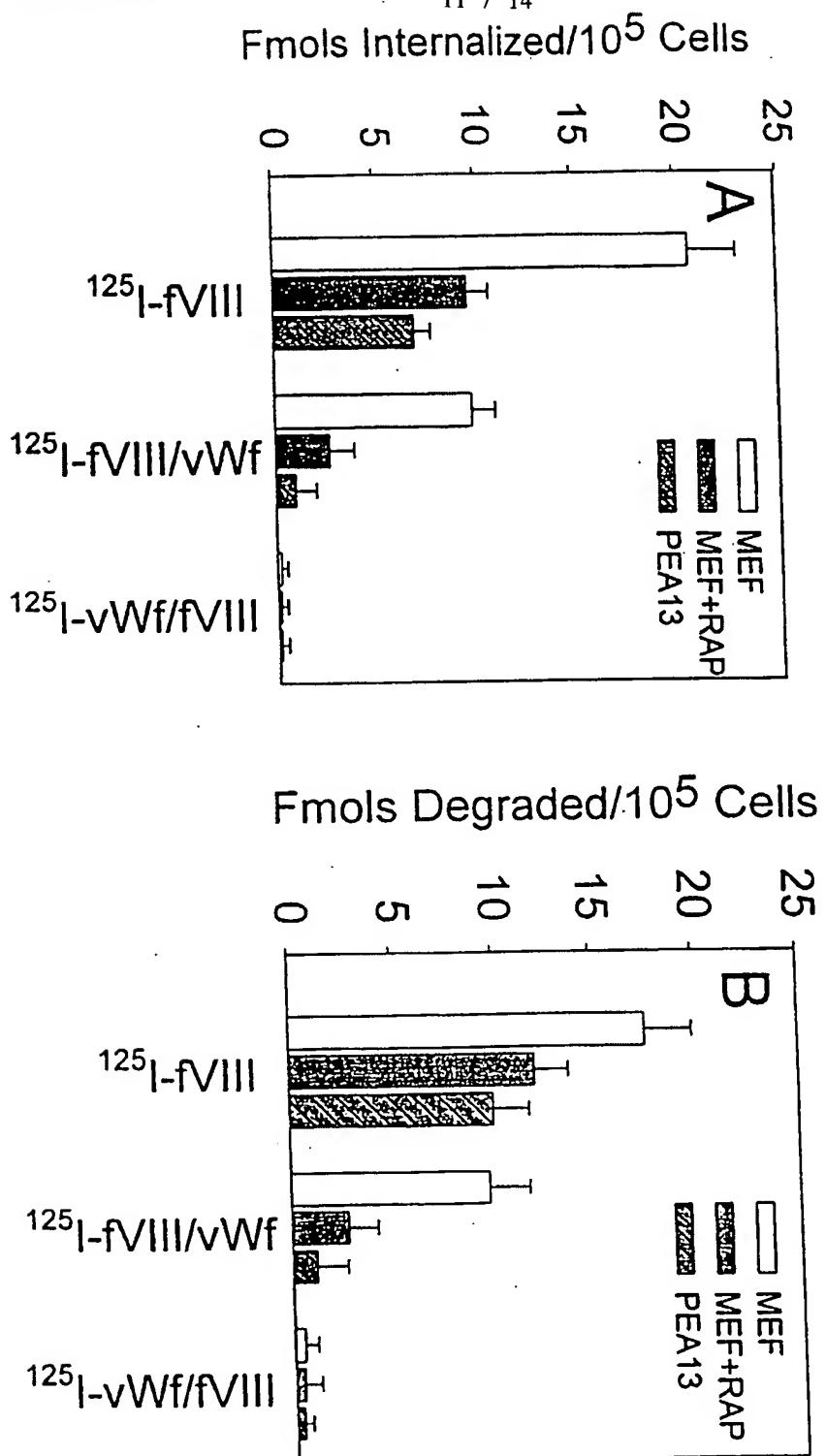


FIG. 9

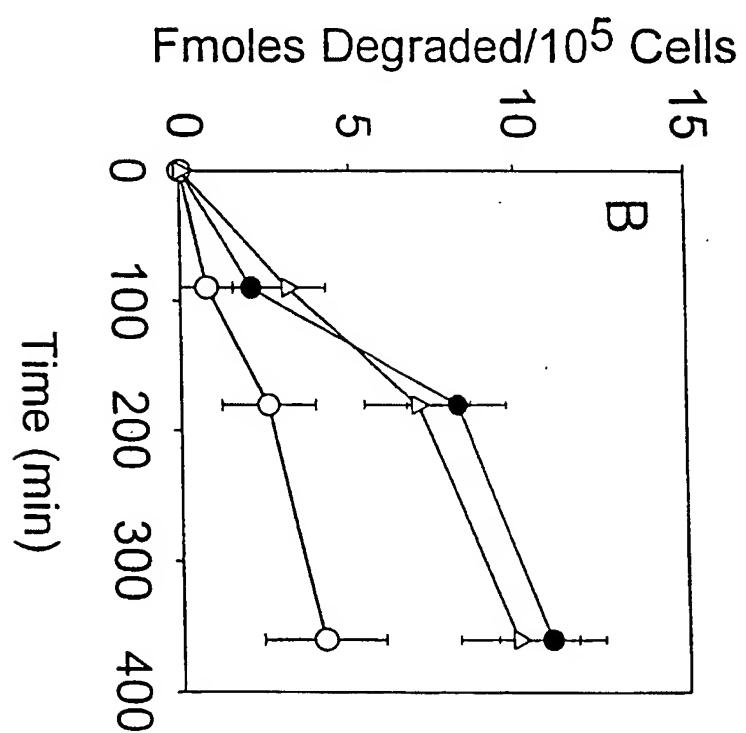
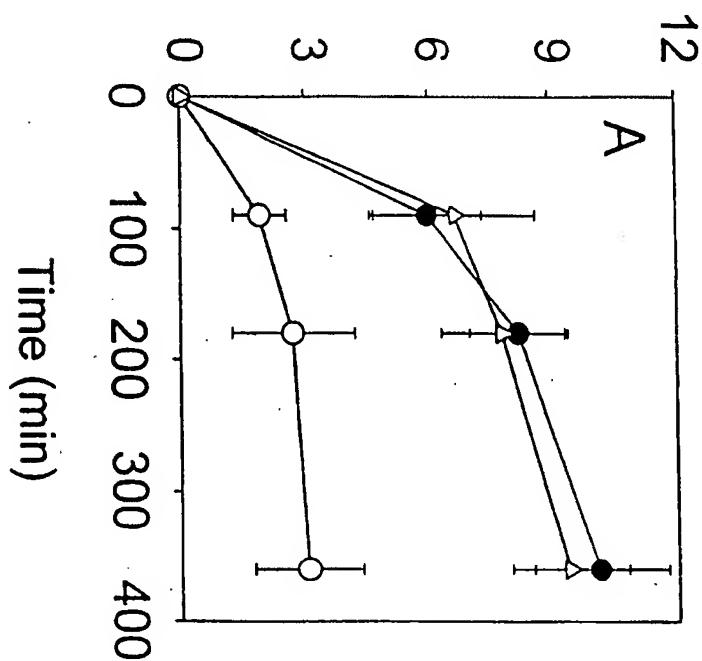
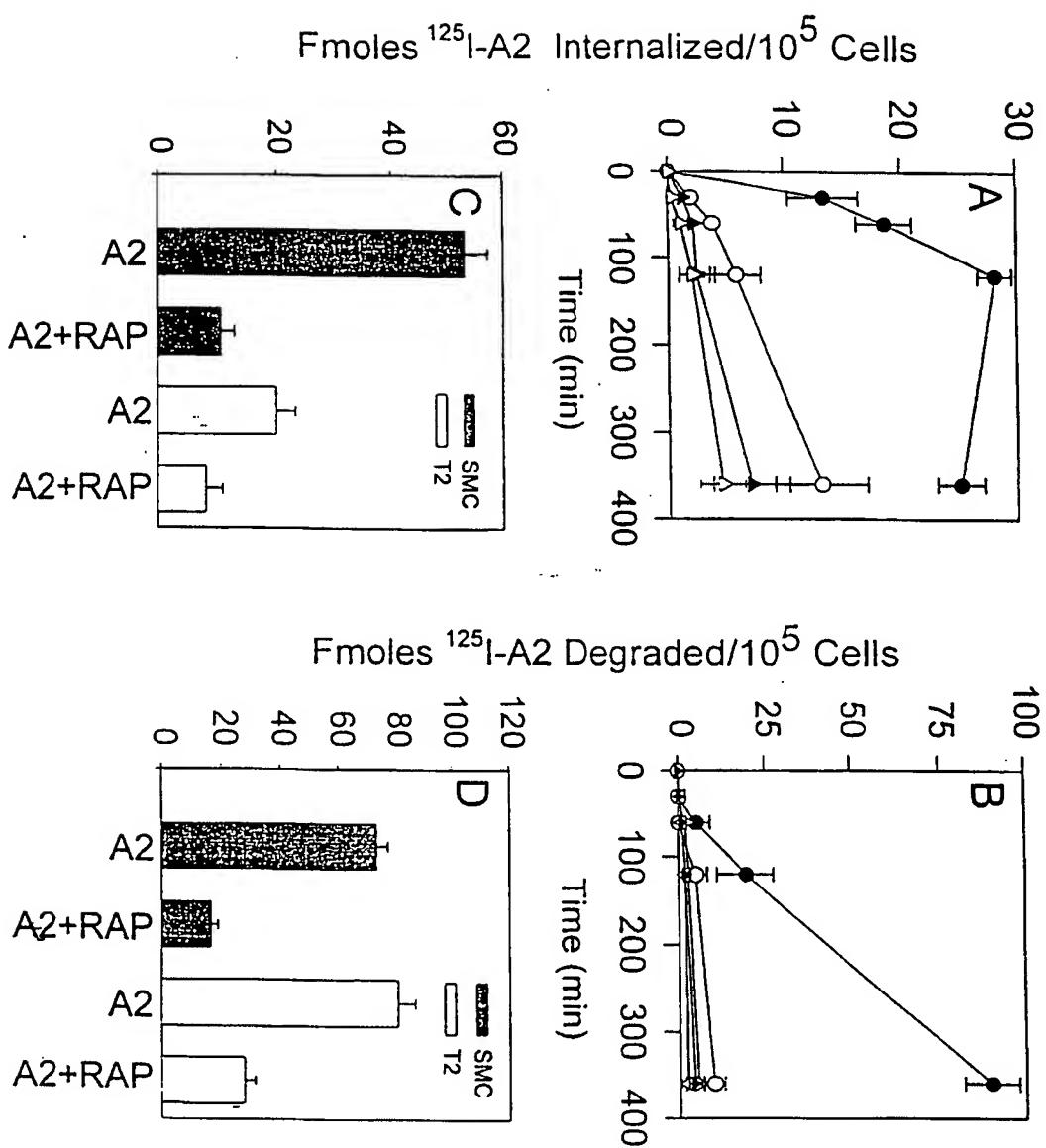
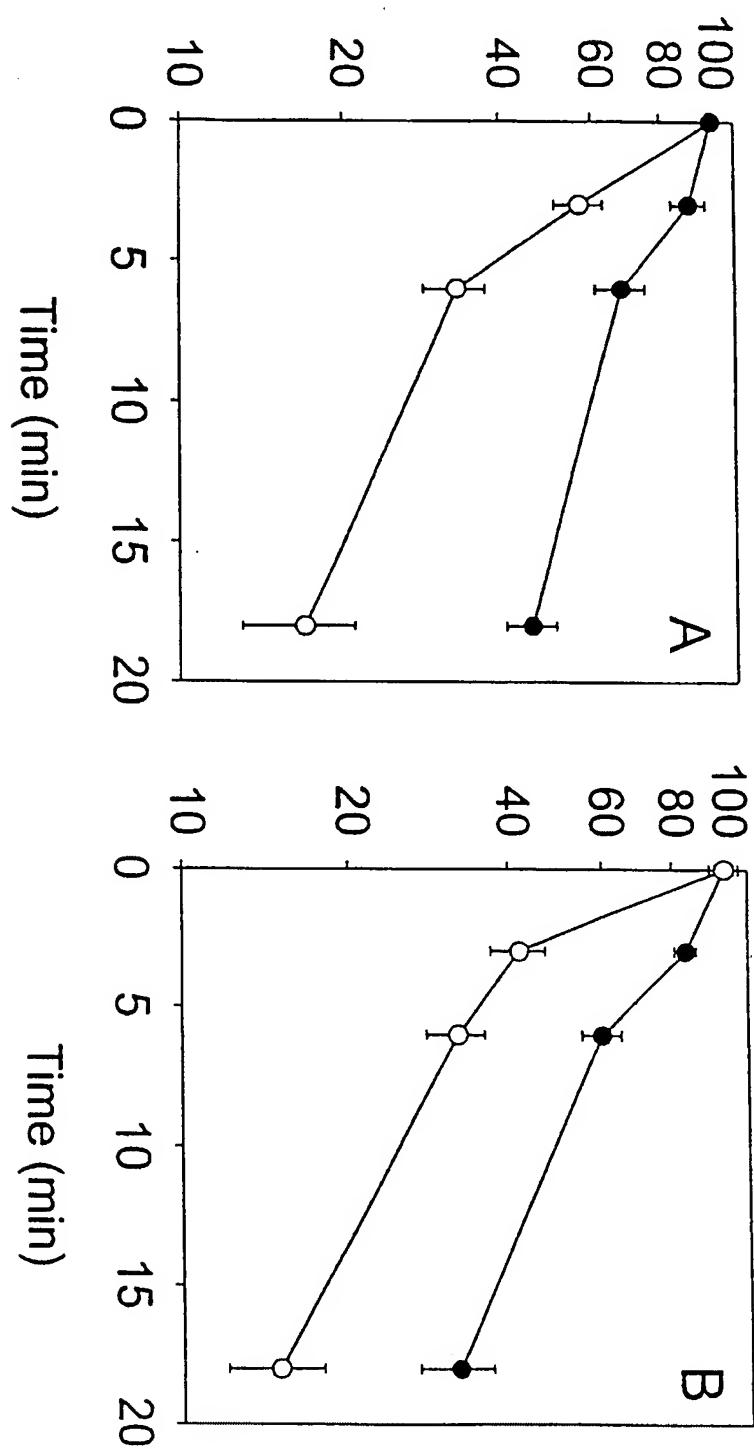
Fmoles Internalized/ $10^5$  Cells.

FIG. 10

FIG. 11



## 125I-Radioactivity Remaining in Plasma (%)



-1-

## SEQUENCE LISTING

<110> The American National Red Cross  
Saenko, Evgeni L.  
Strickland, Dudley K.

<120> Methods of Reducing Factor VIII Clearance and  
Compositions Therefor

<130> 1327.059PC01

<140>

<141>

<150> US 60/135,847

<151> 1999-05-24

<160> 5

<170> PatentIn Ver. 2.0

<210> 1

<211> 8967

<212> DNA

<213> Homo sapiens

<220>

<221> sig\_peptide

<222> (110)..(166)

<220>

<221> mat\_peptide

<222> (167)..(7162)

<220>

<221> CDS

<222> (110)..(7162)

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gaagaattaa ccttttgctt ctccagttga acatttgttag caataagtc atg caa ata 118

Met Gln Ile

-2-

gag ctc tcc acc tgc ttc ttt ctg tgc ctt ttg cga ttc tgc ttt agt 166  
 Glu Leu Ser Thr Cys Phe Phe Leu Cys Leu Leu Arg Phe Cys Phe Ser  
 -15 -10 -5 -1

gcc acc aga aga tac tac ctg ggt gca gtg gaa ctg tca tgg gac tat 214  
 Ala Thr Arg Arg Tyr Tyr Leu Gly Ala Val Glu Leu Ser Trp Asp Tyr  
 1 5 10 15

atg caa agt gat ctc ggt gag ctg cct gtg gac gca aga ttt cct cct 262  
 Met Gln Ser Asp Leu Gly Glu Leu Pro Val Asp Ala Arg Phe Pro Pro  
 20 25 30

aga gtg cca aaa tct ttt cca ttc aac acc tca gtc gtg tac aaa aag 310  
 Arg Val Pro Lys Ser Phe Pro Phe Asn Thr Ser Val Val Tyr Lys Lys  
 35 40 45

act ctg ttt gta gaa ttc acg gat cac ctt ttc aac atc gct aag cca 358  
 Thr Leu Phe Val Glu Phe Thr Asp His Leu Phe Asn Ile Ala Lys Pro  
 50 55 60

agg cca ccc tgg atg ggt ctg cta ggt cct acc atc cag gct gag gtt 406  
 Arg Pro Pro Trp Met Gly Leu Leu Gly Pro Thr Ile Gln Ala Glu Val  
 65 70 75 80

tat gat aca gtg gtc att aca ctt aag aac atg gct tcc cat cct gtc 454  
 Tyr Asp Thr Val Val Ile Thr Leu Lys Asn Met Ala Ser His Pro Val  
 85 90 95

agt ctt cat gct gtt ggt gta tcc tac tgg aaa gct tct gag gga gct 502  
 Ser Leu His Ala Val Gly Val Ser Tyr Trp Lys Ala Ser Glu Gly Ala  
 100 105 110

gaa tat gat gat cag acc agt caa agg gag aaa gaa gat gat aaa gtc 550  
 Glu Tyr Asp Asp Gln Thr Ser Gln Arg Glu Lys Glu Asp Asp Lys Val  
 115 120 125

ttc cct ggt gga agc cat aca tat gtc tgg cag gtc ctg aaa gag aat 598  
 Phe Pro Gly Gly Ser His Thr Tyr Val Trp Gln Val Leu Lys Glu Asn  
 130 135 140

ggt cca atg gcc tct gac cca ctg tgc ctt acc tac tca tat ctt tct 646  
 Gly Pro Met Ala Ser Asp Pro Leu Cys Leu Thr Tyr Ser Tyr Leu Ser  
 145 150 155 160

cat gtg gac ctg gta aaa gac ttg aat tca ggc ctc att gga gcc cta 694

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His Val Asp Leu Val Lys Asp Leu Asn Ser Gly Leu Ile Gly Ala Leu			
165	170	175	
ct a gta tgt aga gaa ggg agt ctg gcc aag gaa aag aca cag acc ttg	742		
Leu Val Cys Arg Glu Gly Ser Leu Ala Lys Glu Lys Thr Gln Thr Leu			
180	185	190	
cac aaa ttt ata cta ctt ttt gct gta ttt gat gaa ggg aaa agt tgg	790		
His Lys Phe Ile Leu Leu Phe Ala Val Phe Asp Glu Gly Lys Ser Trp			
195	200	205	
cac tca gaa aca aag aac tcc ttg atg cag gat agg gat gct gca tct	838		
His Ser Glu Thr Lys Asn Ser Leu Met Gln Asp Arg Asp Ala Ala Ser			
210	215	220	
gct cgg gcc tgg cct aaa atg cac aca gtc aat ggt tat gta aac agg	886		
Ala Arg Ala Trp Pro Lys Met His Thr Val Asn Gly Tyr Val Asn Arg			
225	230	235	240
tct ctg cca ggt ctg att gga tgc cac agg aaa tca gtc tat tgg cat	934		
Ser Leu Pro Gly Leu Ile Gly Cys His Arg Lys Ser Val Tyr Trp His			
245	250	255	
gtg att gga atg ggc acc act cct gaa gtg cac tca ata ttc ctc gaa	982		
Val Ile Gly Met Gly Thr Thr Pro Glu Val His Ser Ile Phe Leu Glu			
260	265	270	
ggt cac aca ttt ctt gtg agg aac cat cgc cag gcg tcc ttg gaa atc	1030		
Gly His Thr Phe Leu Val Arg Asn His Arg Gln Ala Ser Leu Glu Ile			
275	280	285	
tcg cca ata act ttc ctt act gct caa aca ctc ttg atg gac ctt gga	1078		
Ser Pro Ile Thr Phe Leu Thr Ala Gln Thr Leu Leu Met Asp Leu Gly			
290	295	300	
cag ttt cta ctg ttt tgt cat atc tct tcc cac caa cat gat ggc atg	1126		
Gln Phe Leu Leu Phe Cys His Ile Ser Ser His Gln His Asp Gly Met			
305	310	315	320
gaa gct tat gtc aaa gta gac agc tgt cca gag gaa ccc caa cta cga	1174		
Glu Ala Tyr Val Lys Val Asp Ser Cys Pro Glu Glu Pro Gln Leu Arg			
325	330	335	
atg aaa aat aat gaa gaa gcg gaa gac tat gat gat gat ctt act gat	1222		
Met Lys Asn Asn Glu Glu Ala Glu Asp Tyr Asp Asp Leu Thr Asp			

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340	345	350	
tct gaa atg gat gtg gtc agg ttt gat gat gac aac tct cct tcc ttt 1270			
Ser Glu Met Asp Val Val Arg Phe Asp Asp Asp Asn Ser Pro Ser Phe			
355	360	365	
atc caa att cgc tca gtt gcc aag aag cat cct aaa act tgg gta cat 1318			
Ile Gln Ile Arg Ser Val Ala Lys Lys His Pro Lys Thr Trp Val His			
370	375	380	
tac att gct gct gaa gag gag gac tgg gac tat gct ccc tta gtc ctc 1366			
Tyr Ile Ala Ala Glu Glu Asp Trp Asp Tyr Ala Pro Leu Val Leu			
385	390	395	400
gcc ccc gat gac aga agt tat aaa agt caa tat ttg aac aat ggc cct 1414			
Ala Pro Asp Asp Arg Ser Tyr Lys Ser Gln Tyr Leu Asn Asn Gly Pro			
405	410	415	
cag cgg att ggt agg aag tac aaa aaa gtc cga ttt atg gca tac aca 1462			
Gln Arg Ile Gly Arg Lys Tyr Lys Lys Val Arg Phe Met Ala Tyr Thr			
420	425	430	
gat gaa acc ttt aag act cgt gaa gct att cag cat gaa tca gga atc 1510			
Asp Glu Thr Phe Lys Thr Arg Glu Ala Ile Gln His Glu Ser Gly Ile			
435	440	445	
ttg gga cct tta ctt tat ggg gaa gtt gga gac aca ctg ttg att ata 1558			
Leu Gly Pro Leu Leu Tyr Gly Glu Val Gly Asp Thr Leu Leu Ile Ile			
450	455	460	
ttt aag aat caa gca agc aga cca tat aac atc tac cct cac gga atc 1606			
Phe Lys Asn Gln Ala Ser Arg Pro Tyr Asn Ile Tyr Pro His Gly Ile			
465	470	475	480
act gat gtc cgt cct ttg tat tca agg aga tta cca aaa ggt gta aaa 1654			
Thr Asp Val Arg Pro Leu Tyr Ser Arg Arg Leu Pro Lys Gly Val Lys			
485	490	495	
cat ttg aag gat ttt cca att ctg cca gga gaa ata ttc aaa tat aaa 1702			
His Leu Lys Asp Phe Pro Ile Leu Pro Gly Glu Ile Phe Lys Tyr Lys			
500	505	510	
tgg aca gtg act gta gaa gat ggg cca act aaa tca gat cct cggtgc 1750			
Trp Thr Val Thr Val Glu Asp Gly Pro Thr Lys Ser Asp Pro Arg Cys			
515	520	525	

-5-

ctg acc cgc tat tac tct agt ttc gtt aat atg gag aga gat cta gct	1798		
Leu Thr Arg Tyr Tyr Ser Ser Phe Val Asn Met Glu Arg Asp Leu Ala			
530	535	540	
tca gga ctc att ggc cct ctc ctc atc tgc tac aaa gaa tct gta gat	1846		
Ser Gly Leu Ile Gly Pro Leu Leu Ile Cys Tyr Lys Glu Ser Val Asp			
545	550	555	560
caa aga gga aac cag ata atg tca gac aag agg aat gtc atc ctg ttt	1894		
Gln Arg Gly Asn Gln Ile Met Ser Asp Lys Arg Asn Val Ile Leu Phe			
565	570	575	
tct gta ttt gat gag aac cga agc tgg tac ctc aca gag aat ata caa	1942		
Ser Val Phe Asp Glu Asn Arg Ser Trp Tyr Leu Thr Glu Asn Ile Gln			
580	585	590	
cgc ttt ctc ccc aat cca gct gga gtg cag ctt gag gat cca gag ttc	1990		
Arg Phe Leu Pro Asn Pro Ala Gly Val Gln Leu Glu Asp Pro Glu Phe			
595	600	605	
caa gcc tcc aac atc atg cac agc atc aat ggc tat gtt ttt gat agt	2038		
Gln Ala Ser Asn Ile Met His Ser Ile Asn Gly Tyr Val Phe Asp Ser			
610	615	620	
ttg cag ttg tca gtt tgt ttg cat gag gtg gca tac tgg tac att cta	2086		
Leu Gln Leu Ser Val Cys Leu His Glu Val Ala Tyr Trp Tyr Ile Leu			
625	630	635	640
agc att gga gca cag act gac ttc ctt tct gtc ttc ttc tct gga tat	2134		
Ser Ile Gly Ala Gln Thr Asp Phe Leu Ser Val Phe Phe Ser Gly Tyr			
645	650	655	
acc ttc aaa cac aaa atg gtc tat gaa gac aca ctc acc cta ttc cca	2182		
Thr Phe Lys His Lys Met Val Tyr Glu Asp Thr Leu Thr Leu Phe Pro			
660	665	670	
ttc tca gga gaa act gtc ttc atg tcg atg gaa aac cca ggt cta tgg	2230		
Phe Ser Gly Glu Thr Val Phe Met Ser Met Glu Asn Pro Gly Leu Trp			
675	680	685	
att ctg ggg tgc cac aac tca gac ttt cgg aac aga ggc atg acc gcc	2278		
Ile Leu Gly Cys His Asn Ser Asp Phe Arg Asn Arg Gly Met Thr Ala			
690	695	700	

-6-

tta	ctg	aag	gtt	tct	agt	tgt	gac	aag	aac	act	ggt	gat	tat	tac	gag	2326
Leu	Leu	Lys	Val	Ser	Ser	Cys	Asp	Lys	Asn	Thr	Gly	Asp	Tyr	Tyr	Glu	
705				710					715				720			
gac	agt	tat	gaa	gat	att	tca	gca	tac	ttg	ctg	agt	aaa	aac	aat	gcc	2374
Asp	Ser	Tyr	Glu	Asp	Ile	Ser	Ala	Tyr	Leu	Leu	Ser	Lys	Asn	Asn	Ala	
725					730							735				
att	gaa	cca	aga	agc	ttc	tcc	cag	aat	tca	aga	cac	cgt	agc	act	agg	2422
Ile	Glu	Pro	Arg	Ser	Phe	Ser	Gln	Asn	Ser	Arg	His	Arg	Ser	Thr	Arg	
740					745							750				
caa	aag	caa	ttt	aat	gcc	acc	aca	att	cca	gaa	aat	gac	ata	gag	aag	2470
Gln	Lys	Gln	Phe	Asn	Ala	Thr	Thr	Ile	Pro	Glu	Asn	Asp	Ile	Glu	Lys	
755					760							765				
act	gac	cct	tgg	ttt	gca	cac	aga	aca	cct	atg	cct	aaa	ata	caa	aat	2518
Thr	Asp	Pro	Trp	Phe	Ala	His	Arg	Thr	Pro	Met	Pro	Lys	Ile	Gln	Asn	
770					775							780				
gtc	tcc	tct	agt	gat	ttg	ttg	atg	ctc	ttg	cga	cag	agt	cct	act	cca	2566
Val	Ser	Ser	Ser	Asp	Leu	Leu	Met	Leu	Leu	Arg	Gln	Ser	Pro	Thr	Pro	
785					790							795			800	
cat	ggg	cta	tcc	tta	tct	gat	ctc	caa	gaa	gcc	aaa	tat	gag	act	ttt	2614
His	Gly	Ileu	Ser	Ileu	Ser	Asp	Leu	Gln	Glu	Ala	Lys	Tyr	Glu	Thr	Phe	
805					810							815				
tct	gat	gat	cca	tca	cct	gga	gca	ata	gac	agt	aat	aac	agc	ctg	tct	2662
Ser	Asp	Asp	Pro	Ser	Pro	Gly	Ala	Ile	Asp	Ser	Asn	Asn	Ser	Leu	Ser	
820					825							830				
gaa	atg	aca	cac	ttc	agg	cca	cag	ctc	cat	cac	agt	ggg	gac	atg	gta	2710
Glu	Met	Thr	His	Phe	Arg	Pro	Gln	Leu	His	His	Ser	Gly	Asp	Met	Val	
835					840							845				
ttt	acc	cct	gag	tca	ggc	ctc	caa	tta	aga	tta	aat	gag	aaa	ctg	ggg	2758
Phe	Thr	Pro	Glu	Ser	Gly	Leu	Gln	Leu	Arg	Leu	Asn	Glu	Lys	Leu	Gly	
850					855							860				
aca	act	gca	aca	aca	gag	ttg	aag	aaa	ctt	gat	ttc	aaa	gtt	tct	agt	2806
Thr	Thr	Ala	Ala	Thr	Glu	Leu	Lys	Lys	Leu	Asp	Phe	Lys	Val	Ser	Ser	
865					870							875			880	
aca	tca	aat	aat	ctg	att	tca	aca	att	cca	tca	gac	aat	ttg	gca	gca	2854

-7-

Thr Ser Asn Asn Leu Ile Ser Thr Ile Pro Ser Asp Asn Leu Ala Ala			
885	890	895	
ggt act gat aat aca agt tcc tta gga ccc cca agt atg cca gtt cat 2902			
Gly Thr Asp Asn Thr Ser Ser Leu Gly Pro Pro Ser Met Pro Val His			
900	905	910	
tat gat agt caa tta gat acc act cta ttt ggc aaa aag tca tct ccc 2950			
Tyr Asp Ser Gln Leu Asp Thr Thr Leu Phe Gly Lys Lys Ser Ser Pro			
915	920	925	
ctt act gag tct ggt gga cct ctg agc ttg agt gaa gaa aat aat gat 2998			
Leu Thr Glu Ser Gly Gly Pro Leu Ser Leu Ser Glu Glu Asn Asn Asp			
930	935	940	
tca aag ttg tta gaa tca ggt tta atg aat agc caa gaa agt tca tgg 3046			
Ser Lys Leu Leu Glu Ser Gly Leu Met Asn Ser Gln Glu Ser Ser Trp			
945	950	955	960
gga aaa aat gta tcg tca aca gag agt ggt agg tta ttt aaa ggg aaa 3094			
Gly Lys Asn Val Ser Ser Thr Glu Ser Gly Arg Leu Phe Lys Gly Lys			
965	970	975	
aga gct cat gga cct gct ttg ttg act aaa gat aat gcc tta ttc aaa 3142			
Arg Ala His Gly Pro Ala Leu Leu Thr Lys Asp Asn Ala Leu Phe Lys			
980	985	990	
gtt agc atc tct ttg tta aag aca aac aaa act tcc aat aat tca gca 3190			
Val Ser Ile Ser Leu Leu Lys Thr Asn Lys Thr Ser Asn Asn Ser Ala			
995	1000	1005	
act aat aga aag act cac att gat ggc cca tca tta tta att gag aat 3238			
Thr Asn Arg Lys Thr His Ile Asp Gly Pro Ser Leu Leu Ile Glu Asn			
1010	1015	1020	
agt cca tca gtc tgg caa aat ata tta gaa agt gac act gag ttt aaa 3286			
Ser Pro Ser Val Trp Gln Asn Ile Leu Glu Ser Asp Thr Glu Phe Lys			
1025	1030	1035	1040
aaa gtg aca cct ttg att cat gac aga atg ctt atg gac aaa aat gct 3334			
Lys Val Thr Pro Leu Ile His Asp Arg Met Leu Met Asp Lys Asn Ala			
1045	1050	1055	
aca gct ttg agg cta aat cat atg tca aat aaa act act tca tca aaa 3382			
Thr Ala Leu Arg Leu Asn His Met Ser Asn Lys Thr Thr Ser Ser Lys			

-8-

1060	1065	1070	
aac atg gaa atg gtc caa cag aaa aaa gag ggc ccc att cca cca gat			3430
Asn Met Glu Met Val Gln Gln Lys Lys Glu Gly Pro Ile Pro Pro Asp			
1075	1080	1085	
gca caa aat cca gat atg tcg ttc ttt aag atg cta ttc ttg cca gaa			3478
Ala Gln Asn Pro Asp Met Ser Phe Phe Lys Met Leu Phe Leu Pro Glu			
1090	1095	1100	
tca gca agg tgg ata caa agg act cat gga aag aac tct ctg aac tct			3526
Ser Ala Arg Trp Ile Gln Arg Thr His Gly Lys Asn Ser Leu Asn Ser			
1105	1110	1115	1120
ggg caa ggc ccc agt cca aag caa tta gta tcc tta gga cca gaa aaa			3574
Gly Gln Gly Pro Ser Pro Lys Gln Leu Val Ser Leu Gly Pro Glu Lys			
1125	1130	1135	
tct gtg gaa ggt cag aat ttc ttg tct gag aaa aac aaa gtg gta gta			3622
Ser Val Glu Gly Gln Asn Phe Leu Ser Glu Lys Asn Lys Val Val Val			
1140	1145	1150	
gga aag ggt gaa ttt aca aag gac gta gga ctc aaa gag atg gtt ttt			3670
Gly Lys Gly Glu Phe Thr Lys Asp Val Gly Leu Lys Glu Met Val Phe			
1155	1160	1165	
cca agc agc aga aac cta ttt ctt act aac ttg gat aat tta cat gaa			3718
Pro Ser Ser Arg Asn Leu Phe Leu Thr Asn Leu Asp Asn Leu His Glu			
1170	1175	1180	
aat aat aca cac aat caa gaa aaa aaa att cag gaa gaa ata gaa aag			3766
Asn Asn Thr His Asn Gln Glu Lys Lys Ile Gln Glu Glu Ile Glu Lys			
1185	1190	1195	1200
aag gaa aca tta atc caa gag aat gta gtt ttg cct cag ata cat aca			3814
Lys Glu Thr Leu Ile Gln Glu Asn Val Val Leu Pro Gln Ile His Thr			
1205	1210	1215	
gtg act ggc act aag aat ttc atg aag aac ctt ttc tta ctg agc act			3862
Val Thr Gly Thr Lys Asn Phe Met Lys Asn Leu Phe Leu Leu Ser Thr			
1220	1225	1230	
agg caa aat gta gaa ggt tca tat gac ggg gca tat gct cca gta ctt			3910
Arg Gln Asn Val Glu Gly Ser Tyr Asp Gly Ala Tyr Ala Pro Val Leu			
1235	1240	1245	

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caa gat ttt agg tca tta aat gat tca aca aat aga aca aag aaa cac	3958		
Gln Asp Phe Arg Ser Leu Asn Asp Ser Thr Asn Arg Thr Lys Lys His			
1250	1255	1260	
aca gct cat ttc tca aaa aaa ggg gag gaa gaa aac ttg gaa ggc ttg	4006		
Thr Ala His Phe Ser Lys Lys Gly Glu Glu Asn Leu Glu Gly Leu			
1265	1270	1275	1280
gga aat caa acc aag caa att gta gag aaa tat gca tgc acc aca agg	4054		
Gly Asn Gln Thr Lys Gln Ile Val Glu Lys Tyr Ala Cys Thr Thr Arg			
1285	1290	1295	
ata tct cct aat aca agc cag cag aat ttt gtc acg caa cgt agt aag	4102		
Ile Ser Pro Asn Thr Ser Gln Gln Asn Phe Val Thr Gln Arg Ser Lys			
1300	1305	1310	
aga gct ttg aaa caa ttc aga ctc cca cta gaa gaa aca gaa ctt gaa	4150		
Arg Ala Leu Lys Gln Phe Arg Leu Pro Leu Glu Glu Thr Glu Leu Glu			
1315	1320	1325	
aaa agg ata att gtg gat gac acc tca acc cag tgg tcc aaa aac atg	4198		
Lys Arg Ile Ile Val Asp Asp Thr Ser Thr Gln Trp Ser Lys Asn Met			
1330	1335	1340	
aaa cat ttg acc ccg agc acc ctc aca cag ata gac tac aat gag aag	4246		
Lys His Leu Thr Pro Ser Thr Leu Thr Gln Ile Asp Tyr Asn Glu Lys			
1345	1350	1355	1360
gag aaa ggg gcc att act cag tct ccc tta tca gat tgc ctt acg agg	4294		
Glu Lys Gly Ala Ile Thr Gln Ser Pro Leu Ser Asp Cys Leu Thr Arg			
1365	1370	1375	
agt cat agc atc cct caa gca aat aga tct cca tta ccc att gca aag	4342		
Ser His Ser Ile Pro Gln Ala Asn Arg Ser Pro Leu Pro Ile Ala Lys			
1380	1385	1390	
gta tca tca ttt cca tct att aga cct ata tat ctg acc agg gtc cta	4390		
Val Ser Ser Phe Pro Ser Ile Arg Pro Ile Tyr Leu Thr Arg Val Leu			
1395	1400	1405	
ttc caa gac aac tct tct cat ctt cca gca gca tct tat aga aag aaa	4438		
Phe Gln Asp Asn Ser Ser His Leu Pro Ala Ala Ser Tyr Arg Lys Lys			
1410	1415	1420	

-10-

gat tct ggg gtc caa gaa agc agt cat ttc tta caa gga gcc aaa aaa			4486
Asp Ser Gly Val Gln Glu Ser Ser His Phe Leu Gln Gly Ala Lys Lys			
1425	1430	1435	1440
aat aac ctt tct tta gcc att cta acc ttg gag atg act ggt gat caa			4534
Asn Asn Leu Ser Leu Ala Ile Leu Thr Leu Glu Met Thr Gly Asp Gln			
1445	1450	1455	
aga gag gtt ggc tcc ctg ggg aca agt gcc aca aat tca gtc aca tac			4582
Arg Glu Val Gly Ser Leu Gly Thr Ser Ala Thr Asn Ser Val Thr Tyr			
1460	1465	1470	
aag aaa gtt gag aac act gtt ctc ccg aaa cca gac ttg ccc aaa aca			4630
Lys Lys Val Glu Asn Thr Val Leu Pro Lys Pro Asp Leu Pro Lys Thr			
1475	1480	1485	
tct ggc aaa gtt gaa ttg ctt cca aaa gtt cac att tat cag aag gac			4678
Ser Gly Lys Val Glu Leu Leu Pro Lys Val His Ile Tyr Gln Lys Asp			
1490	1495	1500	
cta ttc cct acg gaa act agc aat ggg tct cct ggc cat ctg gat ctc			4726
Leu Phe Pro Thr Glu Thr Ser Asn Gly Ser Pro Gly His Leu Asp Leu			
1505	1510	1515	1520
gtg gaa ggg agc ctt ctt cag gga aca gag gga gcg att aag tgg aat			4774
Val Glu Gly Ser Leu Leu Gln Gly Thr Glu Gly Ala Ile Lys Trp Asn			
1525	1530	1535	
gaa gca aac aga cct gga aaa gtt ccc ttt ctg aga gta gca aca gaa			4822
Glu Ala Asn Arg Pro Gly Lys Val Pro Phe Leu Arg Val Ala Thr Glu			
1540	1545	1550	
agc tct gca aag act ccc tcc aag cta ttg gat cct ctt gct tgg gat			4870
Ser Ser Ala Lys Thr Pro Ser Lys Leu Leu Asp Pro Leu Ala Trp Asp			
1555	1560	1565	
aac cac tat ggt act cag ata cca aaa gaa gag tgg aaa tcc caa gag			4918
Asn His Tyr Gly Thr Gln Ile Pro Lys Glu Glu Trp Lys Ser Gln Glu			
1570	1575	1580	
aag tca cca gaa aaa aca gct ttt aag aaa aag gat acc att ttg tcc			4966
Lys Ser Pro Glu Lys Thr Ala Phe Lys Lys Lys Asp Thr Ile Leu Ser			
1585	1590	1595	1600
ctg aac gct tgt gaa agc aat cat gca ata gca gca ata aat gag gga			5014

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Leu Asn Ala Cys Glu Ser Asn His Ala Ile Ala Ala Ile Asn Glu Gly 5062  
 1605 1610 1615

caa aat aag ccc gaa ata gaa gtc acc tgg gca aag caa ggt agg act  
 Gln Asn Lys Pro Glu Ile Glu Val Thr Trp Ala Lys Gln Gly Arg Thr  
 1620 1625 1630

gaa agg ctg tgc tct caa aac cca cca gtc ttg aaa cgc cat caa cgg 5110  
 Glu Arg Leu Cys Ser Gln Asn Pro Pro Val Leu Lys Arg His Gln Arg  
 1635 1640 1645

gaa ata act cgt act act ctt cag tca gat caa gag gaa att gac tat 5158  
 Glu Ile Thr Arg Thr Thr Leu Gln Ser Asp Gln Glu Glu Ile Asp Tyr  
 1650 1655 1660

gat gat acc ata tca gtt gaa atg aag aag gaa gat ttt gac att tat 5206  
 Asp Asp Thr Ile Ser Val Glu Met Lys Lys Glu Asp Phe Asp Ile Tyr  
 1665 1670 1675 1680

gat gag gat gaa aat cag agc ccc cgc agc ttt caa aag aaa aca cga 5254  
 Asp Glu Asp Glu Asn Gln Ser Pro Arg Ser Phe Gln Lys Lys Thr Arg  
 1685 1690 1695

cac tat ttt att gct gca gtg gag agg ctc tgg gat tat ggg atg agt 5302  
 His Tyr Phe Ile Ala Ala Val Glu Arg Leu Trp Asp Tyr Gly Met Ser  
 1700 1705 1710

agc tcc cca cat gtt cta aga aac agg gct cag agt ggc agt gtc cct 5350  
 Ser Ser Pro His Val Leu Arg Asn Arg Ala Gln Ser Gly Ser Val Pro  
 1715 1720 1725

cag ttc aag aaa gtt gtt ttc cag gaa ttt act gat ggc tcc ttt act 5398  
 Gln Phe Lys Lys Val Val Phe Gln Glu Phe Thr Asp Gly Ser Phe Thr  
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cag ccc tta tac cgt gga gaa cta aat gaa cat ttg gga ctc ctg ggg 5446  
 Gln Pro Leu Tyr Arg Gly Glu Leu Asn Glu His Leu Gly Leu Leu Gly  
 1745 1750 1755 1760

cca tat ata aga gca gaa gtt gaa gat aat atc atg gta act ttc aga 5494  
 Pro Tyr Ile Arg Ala Glu Val Glu Asp Asn Ile Met Val Thr Phe Arg  
 1765 1770 1775

aat cag gcc tct cgt ccc tat tcc ttc tat tct agc ctt att tct tat 5542  
 Asn Gln Ala Ser Arg Pro Tyr Ser Phe Tyr Ser Ser Leu Ile Ser Tyr

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1780	1785	1790	
gag gaa gat cag agg caa gga gca gaa cct aga aaa aac ttt gtc aag			5590
Glu Glu Asp Gln Arg Gln Gly Ala Glu Pro Arg Lys Asn Phe Val Lys			
1795	1800	1805	
cct aat gaa acc aaa act tac ttt tgg aaa gtg caa cat cat atg gca			5638
Pro Asn Glu Thr Lys Thr Tyr Phe Trp Lys Val Gln His His Met Ala			
1810	1815	1820	
ccc act aaa gat gag ttt gac tgc aaa gcc tgg gct tat ttc tct gat			5686
Pro Thr Lys Asp Glu Phe Asp Cys Lys Ala Trp Ala Tyr Phe Ser Asp			
1825	1830	1835	1840
gtt gac ctg gaa aaa gat gtg cac tca ggc ctg att gga ccc ctt ctg			5734
Val Asp Leu Glu Lys Asp Val His Ser Gly Leu Ile Gly Pro Leu Leu			
1845	1850	1855	
gtc tgc cac act aac aca ctg aac cct gct cat ggg aga caa gtg aca			5782
Val Cys His Thr Asn Thr Leu Asn Pro Ala His Gly Arg Gln Val Thr			
1860	1865	1870	
gta cag gaa ttt gct ctg ttt ttc acc atc ttt gat gag acc aaa agc			5830
Val Gln Glu Phe Ala Leu Phe Phe Thr Ile Phe Asp Glu Thr Lys Ser			
1875	1880	1885	
tgg tac ttc act gaa aat atg gaa aga aac tgc agg gct ccc tgc aat			5878
Trp Tyr Phe Thr Glu Asn Met Glu Arg Asn Cys Arg Ala Pro Cys Asn			
1890	1895	1900	
atc cag atg gaa gat ccc act ttt aaa gag aat tat cgc ttc cat gca			5926
Ile Gln Met Glu Asp Pro Thr Phe Lys Glu Asn Tyr Arg Phe His Ala			
1905	1910	1915	1920
atc aat ggc tac ata atg gat aca cta cct ggc tta gta atg gct cag			5974
Ile Asn Gly Tyr Ile Met Asp Thr Leu Pro Gly Leu Val Met Ala Gln			
1925	1930	1935	
gat caa agg att cga tgg tat ctg ctc agc atg ggc agc aat gaa aac			6022
Asp Gln Arg Ile Arg Trp Tyr Leu Leu Ser Met Gly Ser Asn Glu Asn			
1940	1945	1950	
atc cat tct att cat ttc agt gga cat gtg ttc act gta cga aaa aaa			6070
Ile His Ser Ile His Phe Ser Gly His Val Phe Thr Val Arg Lys Lys			
1955	1960	1965	

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gag gag tat aaa atg gca ctg tac aat ctc tat cca ggt gtt ttt gag 6118  
 Glu Glu Tyr Lys Met Ala Leu Tyr Asn Leu Tyr Pro Gly Val Phe Glu  
 1970 1975 1980

aca gtg gaa atg tta cca tcc aaa gct gga att tgg cgg gtg gaa tgc 6166  
 Thr Val Glu Met Leu Pro Ser Lys Ala Gly Ile Trp Arg Val Glu Cys  
 1985 1990 1995 2000

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 2005 2010 2015

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 2020 2025 2030

aga gat ttt cag att aca gct tca gga caa tat gga cag tgg gcc cca 6310  
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 2035 2040 2045

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 Lys Leu Ala Arg Leu His Tyr Ser Gly Ser Ile Asn Ala Trp Ser Thr  
 2050 2055 2060

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 Lys Glu Pro Phe Ser Trp Ile Lys Val Asp Leu Leu Ala Pro Met Ile  
 2065 2070 2075 2080

att cac ggc atc aag acc cag ggt gcc cgt cag aag ttc tcc agc ctc 6454  
 Ile His Gly Ile Lys Thr Gln Gly Ala Arg Gln Lys Phe Ser Ser Leu  
 2085 2090 2095

tac atc tct cag ttt atc atc atg tat agt ctt gat ggg aag aag tgg 6502  
 Tyr Ile Ser Gln Phe Ile Ile Met Tyr Ser Leu Asp Gly Lys Lys Trp  
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 2115 2120 2125

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 Asn Val Asp Ser Ser Gly Ile Lys His Asn Ile Phe Asn Pro Pro Ile  
 2130 2135 2140

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att gct cga tac atc cgt ttg cac cca act cat tat agc att cgc agc	6646
Ile Ala Arg Tyr Ile Arg Leu His Pro Thr His Tyr Ser Ile Arg Ser	
2145 2150 2155 2160	
act ctt cgc atg gag ttg atg ggc tgt gat tta aat agt tgc agc atg	6694
Thr Leu Arg Met Glu Leu Met Gly Cys Asp Leu Asn Ser Cys Ser Met	
2165 2170 2175	
cca ttg gga atg gag agt aaa gca ata tca gat gca cag att act gct	6742
Pro Leu Gly Met Glu Ser Lys Ala Ile Ser Asp Ala Gln Ile Thr Ala	
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Ser Ser Tyr Phe Thr Asn Met Phe Ala Thr Trp Ser Pro Ser Lys Ala	
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cga ctt cac ctc caa ggg agg agt aat gcc tgg aga cct cag gtg aat	6838
Arg Leu His Leu Gln Gly Arg Ser Asn Ala Trp Arg Pro Gln Val Asn	
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Asn Pro Lys Glu Trp Leu Gln Val Asp Phe Gln Lys Thr Met Lys Val	
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Val Lys Glu Phe Leu Ile Ser Ser Gln Asp Gly His Gln Trp Thr	
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Ser Phe Thr Pro Val Val Asn Ser Leu Asp Pro Pro Leu Leu Thr Arg	
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Tyr Leu Arg Ile His Pro Gln Ser Trp Val His Gln Ile Ala Leu Arg	
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Met Glu Val Leu Gly Cys Glu Ala Gln Asp Leu Tyr  
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 <212> PRT  
 <213> Homo sapiens

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Cys Phe Ser Ala Thr Arg Arg Tyr Tyr Leu Gly Ala Val Glu Leu Ser  
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Trp Asp Tyr Met Gln Ser Asp Leu Gly Glu Leu Pro Val Asp Ala Arg  
 15 20 25

Phe Pro Pro Arg Val Pro Lys Ser Phe Pro Phe Asn Thr Ser Val Val  
 30 35 40 45

Tyr Lys Lys Thr Leu Phe Val Glu Phe Thr Asp His Leu Phe Asn Ile  
 50 55 60

Ala Lys Pro Arg Pro Pro Trp Met Gly Leu Leu Gly Pro Thr Ile Gln  
 65 70 75

Ala Glu Val Tyr Asp Thr Val Val Ile Thr Leu Lys Asn Met Ala Ser  
 80 85 90

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His Pro Val Ser Leu His Ala Val Gly Val Ser Tyr Trp Lys Ala Ser  
95 100 105

Glu Gly Ala Glu Tyr Asp Asp Gln Thr Ser Gln Arg Glu Lys Glu Asp  
110 115 120 125

Asp Lys Val Phe Pro Gly Gly Ser His Thr Tyr Val Trp Gln Val Leu  
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Lys Glu Asn Gly Pro Met Ala Ser Asp Pro Leu Cys Leu Thr Tyr Ser  
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Tyr Leu Ser His Val Asp Leu Val Lys Asp Leu Asn Ser Gly Leu Ile  
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Gly Ala Leu Leu Val Cys Arg Glu Gly Ser Leu Ala Lys Glu Lys Thr  
175 180 185

Gln Thr Leu His Lys Phe Ile Leu Leu Phe Ala Val Phe Asp Glu Gly  
190 195 200 205

Lys Ser Trp His Ser Glu Thr Lys Asn Ser Leu Met Gln Asp Arg Asp  
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Ala Ala Ser Ala Arg Ala Trp Pro Lys Met His Thr Val Asn Gly Tyr  
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Val Asn Arg Ser Leu Pro Gly Leu Ile Gly Cys His Arg Lys Ser Val  
240 245 250

Tyr Trp His Val Ile Gly Met Gly Thr Thr Pro Glu Val His Ser Ile  
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Phe Leu Glu Gly His Thr Phe Leu Val Arg Asn His Arg Gln Ala Ser  
270 275 280 285

Leu Glu Ile Ser Pro Ile Thr Phe Leu Thr Ala Gln Thr Leu Leu Met  
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Asp Leu Gly Gln Phe Leu Leu Phe Cys His Ile Ser Ser His Gln His  
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Asp Gly Met Glu Ala Tyr Val Lys Val Asp Ser Cys Pro Glu Glu Pro  
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Gln Leu Arg Met Lys Asn Asn Glu Glu Ala Glu Asp Tyr Asp Asp Asp  
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Leu Thr Asp Ser Glu Met Asp Val Val Arg Phe Asp Asp Asp Asn Ser  
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Pro Ser Phe Ile Gln Ile Arg Ser Val Ala Lys Lys His Pro Lys Thr  
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Trp Val His Tyr Ile Ala Ala Glu Glu Asp Trp Asp Tyr Ala Pro  
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Leu Val Leu Ala Pro Asp Asp Arg Ser Tyr Lys Ser Gln Tyr Leu Asn  
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Asn Gly Pro Gln Arg Ile Gly Arg Lys Tyr Lys Lys Val Arg Phe Met  
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Ala Tyr Thr Asp Glu Thr Phe Lys Thr Arg Glu Ala Ile Gln His Glu  
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Ser Gly Ile Leu Gly Pro Leu Leu Tyr Gly Glu Val Gly Asp Thr Leu  
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Leu Ile Ile Phe Lys Asn Gln Ala Ser Arg Pro Tyr Asn Ile Tyr Pro  
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His Gly Ile Thr Asp Val Arg Pro Leu Tyr Ser Arg Arg Leu Pro Lys  
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Gly Val Lys His Leu Lys Asp Phe Pro Ile Leu Pro Gly Glu Ile Phe  
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Lys Tyr Lys Trp Thr Val Thr Val Glu Asp Gly Pro Thr Lys Ser Asp  
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Pro Arg Cys Leu Thr Arg Tyr Tyr Ser Ser Phe Val Asn Met Glu Arg  
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Asp Leu Ala Ser Gly Leu Ile Gly Pro Leu Leu Ile Cys Tyr Lys Glu  
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Ser Val Asp Gln Arg Gly Asn Gln Ile Met Ser Asp Lys Arg Asn Val  
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Ile Leu Phe Ser Val Phe Asp Glu Asn Arg Ser Trp Tyr Leu Thr Glu  
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Asn Ile Gln Arg Phe Leu Pro Asn Pro Ala Gly Val Gln Leu Glu Asp  
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Pro Glu Phe Gln Ala Ser Asn Ile Met His Ser Ile Asn Gly Tyr Val  
 610 615 620

Phe Asp Ser Leu Gln Leu Ser Val Cys Leu His Glu Val Ala Tyr Trp  
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Tyr Ile Leu Ser Ile Gly Ala Gln Thr Asp Phe Leu Ser Val Phe Phe  
 640 645 650

Ser Gly Tyr Thr Phe Lys His Lys Met Val Tyr Glu Asp Thr Leu Thr  
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Leu Phe Pro Phe Ser Gly Glu Thr Val Phe Met Ser Met Glu Asn Pro  
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Gly Leu Trp Ile Leu Gly Cys His Asn Ser Asp Phe Arg Asn Arg Gly  
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Tyr Tyr Glu Asp Ser Tyr Glu Asp Ile Ser Ala Tyr Leu Leu Ser Lys  
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Ser Thr Arg Gln Lys Gln Phe Asn Ala Thr Thr Ile Pro Glu Asn Asp  
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Ile Glu Lys Thr Asp Pro Trp Phe Ala His Arg Thr Pro Met Pro Lys  
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Pro Thr Pro His Gly Leu Ser Leu Ser Asp Leu Gln Glu Ala Lys Tyr  
 800 805 810

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815 820 825

Ser Leu Ser Glu Met Thr His Phe Arg Pro Gln Leu His His Ser Gly  
830 835 840 845

Asp Met Val Phe Thr Pro Glu Ser Gly Leu Gln Leu Arg Leu Asn Glu  
850 855 860

Lys Leu Gly Thr Thr Ala Ala Thr Glu Leu Lys Lys Leu Asp Phe Lys  
865 870 875

Val Ser Ser Thr Ser Asn Asn Leu Ile Ser Thr Ile Pro Ser Asp Asn  
880 885 890

Leu Ala Ala Gly Thr Asp Asn Thr Ser Ser Leu Gly Pro Pro Ser Met  
895 900 905

Pro Val His Tyr Asp Ser Gln Leu Asp Thr Thr Leu Phe Gly Lys Lys  
910 915 920 925

Ser Ser Pro Leu Thr Glu Ser Gly Gly Pro Leu Ser Leu Ser Glu Glu  
930 935 940

Asn Asn Asp Ser Lys Leu Leu Glu Ser Gly Leu Met Asn Ser Gln Glu  
945 950 955

Ser Ser Trp Gly Lys Asn Val Ser Ser Thr Glu Ser Gly Arg Leu Phe  
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Lys Gly Lys Arg Ala His Gly Pro Ala Leu Leu Thr Lys Asp Asn Ala  
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Glu Phe Lys Lys Val Thr Pro Leu Ile His Asp Arg Met Leu Met Asp  
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Lys Asn Ala Thr Ala Leu Arg Leu Asn His Met Ser Asn Lys Thr Thr  
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Ser Ser Lys Asn Met Glu Met Val Gln Gln Lys Lys Glu Gly Pro Ile  
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Pro Lys Thr Ser Gly Lys Val Glu Leu Leu Pro Lys Val His Ile Tyr  
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Phe Val Lys Pro Asn Glu Thr Lys Thr Tyr Phe Trp Lys Val Gln His  
1810 1815 1820

His Met Ala Pro Thr Lys Asp Glu Phe Asp Cys Lys Ala Trp Ala Tyr  
1825 1830 1835

Phe Ser Asp Val Asp Leu Glu Lys Asp Val His Ser Gly Leu Ile Gly  
1840 1845 1850

Pro Leu Leu Val Cys His Thr Asn Thr Leu Asn Pro Ala His Gly Arg  
1855 1860 1865

Gln Val Thr Val Gln Glu Phe Ala Leu Phe Phe Thr Ile Phe Asp Glu  
870 1875 1880 1885

Thr Lys Ser Trp Tyr Phe Thr Glu Asn Met Glu Arg Asn Cys Arg Ala  
1890 1895 1900

Pro Cys Asn Ile Gln Met Glu Asp Pro Thr Phe Lys Glu Asn Tyr Arg  
1905 1910 1915

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1920 1925 1930

Met Ala Gln Asp Gln Arg Ile Arg Trp Tyr Leu Leu Ser Met Gly Ser  
1935 1940 1945

Asn Glu Asn Ile His Ser Ile His Phe Ser Gly His Val Phe Thr Val  
950 1955 1960 1965

Arg Lys Lys Glu Glu Tyr Lys Met Ala Leu Tyr Asn Leu Tyr Pro Gly  
1970 1975 1980

Val Phe Glu Thr Val Glu Met Leu Pro Ser Lys Ala Gly Ile Trp Arg  
1985 1990 1995

Val Glu Cys Leu Ile Gly Glu His Leu His Ala Gly Met Ser Thr Leu  
2000 2005 2010

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Phe Leu Val Tyr Ser Asn Lys Cys Gln Thr Pro Leu Gly Met Ala Ser  
2015 2020 2025

Gly His Ile Arg Asp Phe Gln Ile Thr Ala Ser Gly Gln Tyr Gly Gln  
030 2035 2040 2045

Trp Ala Pro Lys Leu Ala Arg Leu His Tyr Ser Gly Ser Ile Asn Ala  
2050 2055 2060

Trp Ser Thr Lys Glu Pro Phe Ser Trp Ile Lys Val Asp Leu Leu Ala  
2065 2070 2075

Pro Met Ile Ile His Gly Ile Lys Thr Gln Gly Ala Arg Gln Lys Phe  
2080 2085 2090

Ser Ser Leu Tyr Ile Ser Gln Phe Ile Ile Met Tyr Ser Leu Asp Gly  
2095 2100 2105

Lys Lys Trp Gln Thr Tyr Arg Gly Asn Ser Thr Gly Thr Leu Met Val  
110 2115 2120 2125

Phe Phe Gly Asn Val Asp Ser Ser Gly Ile Lys His Asn Ile Phe Asn  
2130 2135 2140

Pro Pro Ile Ile Ala Arg Tyr Ile Arg Leu His Pro Thr His Tyr Ser  
2145 2150 2155

Ile Arg Ser Thr Leu Arg Met Glu Leu Met Gly Cys Asp Leu Asn Ser  
2160 2165 2170

Cys Ser Met Pro Leu Gly Met Glu Ser Lys Ala Ile Ser Asp Ala Gln  
2175 2180 2185

Ile Thr Ala Ser Ser Tyr Phe Thr Asn Met Phe Ala Thr Trp Ser Pro  
190 2195 2200 2205

Ser Lys Ala Arg Leu His Leu Gln Gly Arg Ser Asn Ala Trp Arg Pro  
2210 2215 2220

Gln Val Asn Asn Pro Lys Glu Trp Leu Gln Val Asp Phe Gln Lys Thr  
2225 2230 2235

Met Lys Val Thr Gly Val Thr Thr Gln Gly Val Lys Ser Leu Leu Thr  
2240 2245 2250

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Ser Met Tyr Val Lys Glu Phe Leu Ile Ser Ser Ser Gln Asp Gly His  
 2255 . 2260 2265

Gln Trp Thr Leu Phe Phe Gln Asn Gly Lys Val Lys Val Phe Gln Gly  
 270 2275 2280 2285

Asn Gln Asp Ser Phe Thr Pro Val Val Asn Ser Leu Asp Pro Pro Leu  
 2290 2295 2300

Leu Thr Arg Tyr Leu Arg Ile His Pro Gln Ser Trp Val His Gln Ile  
 2305 2310 2315

Ala Leu Arg Met Glu Val Leu Gly Cys Glu Ala Gln Asp Leu Tyr  
 2320 2325 2330

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<222> (116)..(1084)

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 Met Ala Pro Arg Arg Val Arg Ser Phe Leu Arg Gly  
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ctc ccg gcg ctg cta ctg ctg ctc ttc ctc ggg ccc tgg ccc gct 97  
 Leu Pro Ala Leu Leu Leu Leu Leu Phe Leu Gly Pro Trp Pro Ala  
 -20 -15 -10

gcg agc cac ggc ggc aag tac tcg cgg gag aag aac cag ccc aag ccg 145  
 Ala Ser His Gly Gly Lys Tyr Ser Arg Glu Lys Asn Gln Pro Lys Pro

-27-

-5	-1	1	5	10
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tcc	ccg	aaa	cgc	gag	tcc	gga	gag	gag	ttc	cgc	atg	gag	aag	ttg	aac	193
Ser	Pro	Lys	Arg	Glu	Ser	Gly	Glu	Glu	Phe	Arg	Met	Glu	Lys	Leu	Asn	
15									20						25	

cag	ctg	tgg	gag	aag	gcc	cag	cga	ctg	cat	ctt	cct	ccc	gtg	agg	ctg	241
Gln	Leu	Trp	Glu	Lys	Ala	Gln	Arg	Leu	His	Leu	Pro	Pro	Val	Arg	Leu	
30									35					40		

gcc	gag	ctc	cac	gct	gat	ctg	aag	ata	cag	gag	agg	gac	gaa	ctc	gcc	289
Ala	Glu	Leu	His	Ala	Asp	Leu	Lys	Ile	Gln	Glu	Arg	Asp	Glu	Leu	Ala	
45									50					55		

tgg	aag	aaa	cta	aag	ctt	gac	ggc	ttg	gac	gaa	gat	ggg	gag	aag	gaa	337
Trp	Lys	Lys	Leu	Lys	Leu	Asp	Gly	Leu	Asp	Glu	Asp	Gly	Glu	Lys	Glu	
									60					70		

gcg	aga	ctc	ata	cgc	aac	ctc	aat	gtc	atc	ttg	gcc	aag	tat	ggt	ctg	385
Ala	Arg	Leu	Ile	Arg	Asn	Leu	Asn	Val	Ile	Leu	Ala	Lys	Tyr	Gly	Leu	
									75					80	90	

gac	gga	aag	aag	gac	gct	cg	cag	gt	acc	agc	aac	tcc	ctc	agt	ggc	433
Asp	Gly	Lys	Lys	Asp	Ala	Arg	Gln	Val	Thr	Ser	Asn	Ser	Leu	Ser	Gly	
									95					100	105	

acc	cag	gaa	gac	ggg	ctg	gat	gac	ccc	agg	ctg	gaa	aag	ctg	tgg	cac	481
Thr	Gln	Glu	Asp	Gly	Leu	Asp	Asp	Pro	Arg	Leu	Glu	Lys	Leu	Trp	His	
									110					115	120	

aag	g	g	a	g	acc	tct	ggg	aaa	ttc	tcc	ggc	gaa	gaa	ctg	gac	aag	ctc	529
Lys	Ala	Lys	Thr	Ser	Gly	Lys	Phe	Ser	Gly	Glu	Glu	Leu	Asp	Lys	Leu			
									125					130	135			

tgg	cg	g	g	ttc	ctg	cat	cac	aaa	gag	aaa	gtt	cac	gag	tac	aac	gtc	577
Trp	Arg	Glu	Phe	Leu	His	His	Lys	Glu	Lys	Val	His	Glu	Tyr	Asn	Val		
									140					145	150		

ctg	ctg	gag	acc	ctg	agc	agg	acc	gaa	gaa	atc	cac	gag	aac	gtc	att	625
Leu	Leu	Glu	Thr	Leu	Ser	Arg	Thr	Glu	Glu	Ile	His	Glu	Asn	Val	Ile	
									155					160	165	

agc	ccc	tcg	gac	ctg	agc	gac	atc	aag	ggc	agc	gtc	ctg	cac	agc	agg	673
Ser	Pro	Ser	Asp	Leu	Ser	Asp	Ile	Lys	Gly	Ser	Val	Leu	His	Ser	Arg	
									175					180	185	

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cac acg gag ctg aag gag aag ctg cgc agc atc aac cag ggc ctg gac 721  
 His Thr Glu Leu Lys Glu Lys Leu Arg Ser Ile Asn Gln Gly Leu Asp  
 190 195 200

cgc ctg cgc agg gtc agc cac cag ggc tac agc act gag gct gag ttc 769  
 Arg Leu Arg Arg Val Ser His Gln Gly Tyr Ser Thr Glu Ala Glu Phe  
 205 210 215

gag gag ccc agg gtg att gac ctg tgg gac ctg gcg cag tcc gcc aac 817  
 Glu Glu Pro Arg Val Ile Asp Leu Trp Asp Leu Ala Gln Ser Ala Asn  
 220 225 230

ctc acg gac aag gag ctg gag gcg ttc cgg gag gag ctc aag cac ttc 865  
 Leu Thr Asp Lys Glu Leu Ala Phe Arg Glu Glu Leu Lys His Phe  
 235 240 245 250

gaa gcc aaa atc gag aag cac aac cac tac cag aag cag ctg gag att 913  
 Glu Ala Lys Ile Glu Lys His Asn His Tyr Gln Lys Gln Leu Glu Ile  
 255 260 265

gcg cac gag aag ctg agg cac gca gag agc gtg ggc gac ggc gag cgt 961  
 Ala His Glu Lys Leu Arg His Ala Glu Ser Val Gly Asp Gly Glu Arg  
 270 275 280

gtg agc cgc agc cgc gag aag cac gcc ctg ctg gag ggg cgg acc aag 1009  
 Val Ser Arg Ser Arg Glu Lys His Ala Leu Leu Glu Gly Arg Thr Lys  
 285 290 295

gag ctg ggc tac acg gtg aag aag cat ctg cag gac ctg tcc ggc agg 1057  
 Glu Leu Gly Tyr Thr Val Lys Lys His Leu Gln Asp Leu Ser Gly Arg  
 300 305 310

atc tcc aga gct cgg cac aac gaa ctc tgaaggcaact ggggagccca 1104  
 Ile Ser Arg Ala Arg His Asn Glu Leu  
 315 320

gccccggcagg gaagaggcca gcgtgaagga cctgggtctct tggccgtggc atttccgtgg 1164

acagccccgcc gtcaggggtgg ctggggctgg cacgggtgtc gaggcagggaa ggattgtttc 1224

tggtgactgc agccgctgcc gtcgcgacac agggcttggt ggtggtagca tttgggtctg 1284

agatcggccc agctctgact gaaggggctt ggcttccact cagcatcagc gtggcagtca 1344

-29-

ccaccccggt gaggacctcg atgtccagct gctgtcagggt ctgatagtcc tctgctaaaa 1404  
 caacacgatt tacataaaaa atcttacaca tctgccaccc gaaataccat gcacagagtc 1464  
 cttaaaaaat agagtgcagt atttaaacc 1493

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 <212> PRT  
 <213> Homo sapiens

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 Met Ala Pro Arg Arg Val Arg Ser Phe Leu Arg Gly Leu Pro Ala Leu  
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Leu Leu Leu Leu Phe Leu Gly Pro Trp Pro Ala Ala Ser His Gly  
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Gly Lys Tyr Ser Arg Glu Lys Asn Gln Pro Lys Pro Ser Pro Lys Arg  
 -1 1 5 10

Glu Ser Gly Glu Glu Phe Arg Met Glu Lys Leu Asn Gln Leu Trp Glu  
 15 20 25 30

Lys Ala Gln Arg Leu His Leu Pro Pro Val Arg Leu Ala Glu Leu His  
 35 40 45

Ala Asp Leu Lys Ile Gin Glu Arg Asp Glu Leu Ala Trp Lys Lys Leu  
 50 55 60

Lys Leu Asp Gly Leu Asp Glu Asp Gly Glu Lys Glu Ala Arg Leu Ile  
 65 70 75

Arg Asn Leu Asn Val Ile Leu Ala Lys Tyr Gly Leu Asp Gly Lys Lys  
 80 85 90

Asp Ala Arg Gln Val Thr Ser Asn Ser Leu Ser Gly Thr Gln Glu Asp  
 95 100 105 110

Gly Leu Asp Asp Pro Arg Leu Glu Lys Leu Trp His Lys Ala Lys Thr  
 115 120 125

Ser Gly Lys Phe Ser Gly Glu Glu Leu Asp Lys Leu Trp Arg Glu Phe  
 130 135 140

-30-

Leu His His Lys Glu Lys Val His Glu Tyr Asn Val Leu Leu Glu Thr  
145 150 155

Leu Ser Arg Thr Glu Glu Ile His Glu Asn Val Ile Ser Pro Ser Asp  
160 165 170

Leu Ser Asp Ile Lys Gly Ser Val Leu His Ser Arg His Thr Glu Leu  
175 180 185 190

Lys Glu Lys Leu Arg Ser Ile Asn Gln Gly Leu Asp Arg Leu Arg Arg  
195 200 205

Val Ser His Gln Gly Tyr Ser Thr Glu Ala Glu Phe Glu Glu Pro Arg  
210 215 220

Val Ile Asp Leu Trp Asp Leu Ala Gln Ser Ala Asn Leu Thr Asp Lys  
225 230 235

Glu Leu Glu Ala Phe Arg Glu Glu Leu Lys His Phe Glu Ala Lys Ile  
240 245 250

Glu Lys His Asn His Tyr Gln Lys Gln Leu Glu Ile Ala His Glu Lys  
255 260 265 270

Leu Arg His Ala Glu Ser Val Gly Asp Gly Glu Arg Val Ser Arg Ser  
275 280 285

Arg Glu Lys His Ala Leu Leu Glu Gly Arg Thr Lys Glu Leu Gly Tyr  
290 295 300

Thr Val Lys Lys His Leu Gln Asp Leu Ser Gly Arg Ile Ser Arg Ala  
305 310 315

Arg His Asn Glu Leu  
320

<210> 5

<211> 1424

<212> PRT

<213> Homo sapiens

<400> 5

Ala Thr Arg Arg Tyr Tyr Leu Gly Ala Val Glu Leu Ser Trp Asp Tyr

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1	5	10	15
Met Gln Ser Asp Leu Gly Glu Leu Pro Val Asp Ala Arg Phe Pro Pro			
20		25	30
Arg Val Pro Lys Ser Phe Pro Phe Asn Thr Ser Val Val Tyr Lys Lys			
35		40	45
Thr Leu Phe Val Glu Phe Thr Asp His Leu Phe Asn Ile Ala Lys Pro			
50		55	60
Arg Pro Pro Trp Met Gly Leu Leu Gly Pro Thr Ile Gln Ala Glu Val			
65	70	75	80
Tyr Asp Thr Val Val Ile Thr Leu Lys Asn Met Ala Ser His Pro Val			
85		90	95
Ser Leu His Ala Val Gly Val Ser Tyr Trp Lys Ala Ser Glu Gly Ala			
100		105	110
Glu Tyr Asp Asp Gln Thr Ser Gln Arg Glu Lys Glu Asp Asp Lys Val			
115		120	125
Phe Pro Gly Gly Ser His Thr Tyr Val Trp Gln Val Leu Lys Glu Asn			
130		135	140
Gly Pro Met Ala Ser Asp Pro Leu Cys Leu Thr Tyr Ser Tyr Leu Ser			
145	150	155	160
His Val Asp Leu Val Lys Asp Leu Asn Ser Gly Leu Ile Gly Ala Leu			
165		170	175
Leu Val Cys Arg Glu Gly Ser Leu Ala Lys Glu Lys Thr Gln Thr Leu			
180		185	190
His Lys Phe Ile Leu Leu Phe Ala Val Phe Asp Glu Gly Lys Ser Trp			
195	200	205	
His Ser Glu Thr Lys Asn Ser Leu Met Gln Asp Arg Asp Ala Ala Ser			
210	215	220	
Ala Arg Ala Trp Pro Lys Met His Thr Val Asn Gly Tyr Val Asn Arg			
225	230	235	240
Ser Leu Pro Gly Leu Ile Gly Cys His Arg Lys Ser Val Tyr Trp His			

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245	250	255
Val Ile Gly Met Gly Thr Thr Pro Glu Val His Ser Ile Phe Leu Glu		
260	265	270
Gly His Thr Phe Leu Val Arg Asn His Arg Gln Ala Ser Leu Glu Ile		
275	280	285
Ser Pro Ile Thr Phe Leu Thr Ala Gln Thr Leu Leu Met Asp Leu Gly		
290	295	300
Gln Phe Leu Leu Phe Cys His Ile Ser Ser His Gln His Asp Gly Met		
305	310	315
		320
Glu Ala Tyr Val Lys Val Asp Ser Cys Pro Glu Glu Pro Gln Leu Arg		
325	330	335
Met Lys Asn Asn Glu Glu Ala Glu Asp Tyr Asp Asp Asp Leu Thr Asp		
340	345	350
Ser Glu Met Asp Val Val Arg Phe Asp Asp Asp Asn Ser Pro Ser Phe		
355	360	365
Ile Gln Ile Arg Ser Val Ala Lys Lys His Pro Lys Thr Trp Val His		
370	375	380
Tyr Ile Ala Ala Glu Glu Asp Trp Asp Tyr Ala Pro Leu Val Leu		
385	390	395
		400
Ala Pro Asp Asp Arg Ser Tyr Lys Ser Gln Tyr Leu Asn Asn Gly Pro		
405	410	415
Gln Arg Ile Gly Arg Lys Tyr Lys Lys Val Arg Phe Met Ala Tyr Thr		
420	425	430
Asp Glu Thr Phe Lys Thr Arg Glu Ala Ile Gln His Glu Ser Gly Ile		
435	440	445
Leu Gly Pro Leu Leu Tyr Gly Glu Val Gly Asp Thr Leu Leu Ile Ile		
450	455	460
Phe Lys Asn Gln Ala Ser Arg Pro Tyr Asn Ile Tyr Pro His Gly Ile		
465	470	475
		480
Thr Asp Val Arg Pro Leu Tyr Ser Arg Arg Leu Pro Lys Gly Val Lys		

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485 490 495

His Leu Lys Asp Phe Pro Ile Leu Pro Gly Glu Ile Phe Lys Tyr Lys  
 500 505 510

Trp Thr Val Thr Val Glu Asp Gly Pro Thr Lys Ser Asp Pro Arg Cys  
 515 520 525

Leu Thr Arg Tyr Tyr Ser Ser Phe Val Asn Met Glu Arg Asp Leu Ala  
 530 535 540

Ser Gly Leu Ile Gly Pro Leu Leu Ile Cys Tyr Lys Glu Ser Val Asp  
 545 550 555 560

Gln Arg Gly Asn Gln Ile Met Ser Asp Lys Arg Asn Val Ile Leu Phe  
 565 570 575

Ser Val Phe Asp Glu Asn Arg Ser Trp Tyr Leu Thr Glu Asn Ile Gln  
 580 585 590

Arg Phe Leu Pro Asn Pro Ala Gly Val Gln Leu Glu Asp Pro Glu Phe  
 595 600 605

Gln Ala Ser Asn Ile Met His Ser Ile Asn Gly Tyr Val Phe Asp Ser  
 610 615 620

Leu Gln Leu Ser Val Cys Leu His Glu Val Ala Tyr Trp Tyr Ile Leu  
 625 630 635 640

Ser Ile Gly Ala Gln Thr Asp Phe Leu Ser Val Phe Phe Ser Gly Tyr  
 645 650 655

Thr Phe Lys His Lys Met Val Tyr Glu Asp Thr Leu Thr Leu Phe Pro  
 660 665 670

Phe Ser Gly Glu Thr Val Phe Met Ser Met Glu Asn Pro Gly Leu Trp  
 675 680 685

Ile Leu Gly Cys His Asn Ser Asp Phe Arg Asn Arg Gly Met Thr Ala  
 690 695 700

Leu Leu Lys Val Ser Ser Cys Asp Lys Asn Thr Gly Asp Tyr Tyr Glu  
 705 710 715 720

Asp Ser Tyr Glu Asp Ile Ser Ala Tyr Leu Leu Ser Lys Asn Asn Ala

-34-

725

730

735

Ile Glu Pro Arg Glu Ile Thr Arg Thr Thr Leu Gln Ser Asp Gln Glu  
 740 745 750

Glu Ile Asp Tyr Asp Asp Thr Ile Ser Val Glu Met Lys Lys Glu Asp  
 755 760 765

Phe Asp Ile Tyr Asp Glu Asp Glu Asn Gln Ser Pro Arg Ser Phe Gln  
 770 775 780

Lys Lys Thr Arg His Tyr Phe Ile Ala Ala Val Glu Arg Leu Trp Asp  
 785 790 795 800

Tyr Gly Met Ser Ser Ser Pro His Val Leu Arg Asn Arg Ala Gln Ser  
 805 810 815

Gly Ser Val Pro Gln Phe Lys Lys Val Val Phe Gln Glu Phe Thr Asp  
 820 825 830

Gly Ser Phe Thr Gln Pro Leu Tyr Arg Gly Glu Leu Asn Glu His Leu  
 835 840 845

Gly Leu Leu Gly Pro Tyr Ile Arg Ala Glu Val Glu Asp Asn Ile Met  
 850 855 860

Val Thr Phe Arg Asn Gln Ala Ser Arg Pro Tyr Ser Phe Tyr Ser Ser  
 865 870 875 880

Leu Ile Ser Tyr Glu Glu Asp Gln Arg Gln Gly Ala Glu Pro Arg Lys  
 885 890 895

Asn Phe Val Lys Pro Asn Glu Thr Lys Thr Tyr Phe Trp Lys Val Gln  
 900 905 910

His His Met Ala Pro Thr Lys Asp Glu Phe Asp Cys Lys Ala Trp Ala  
 915 920 925

Tyr Phe Ser Asp Val Asp Leu Glu Lys Asp Val His Ser Gly Leu Ile  
 930 935 940

Gly Pro Leu Leu Val Cys His Thr Asn Thr Leu Asn Pro Ala His Gly  
 945 950 955 960

Arg Gln Val Thr Val Gln Glu Phe Ala Leu Phe Phe Thr Ile Phe Asp

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965	970	975
Glu Thr Lys Ser Trp Tyr Phe Thr Glu Asn Met Glu Arg Asn Cys Arg		
980	985	990
Ala Pro Cys Asn Ile Gln Met Glu Asp Pro Thr Phe Lys Glu Asn Tyr		
995	1000	1005
Arg Phe His Ala Ile Asn Gly Tyr Ile Met Asp Thr Leu Pro Gly Leu		
1010	1015	1020
Val Met Ala Gln Asp Gln Arg Ile Arg Trp Tyr Leu Leu Ser Met Gly		
1025	1030	1035
Ser Asn Glu Asn Ile His Ser Ile His Phe Ser Gly His Val Phe Thr		
1045	1050	1055
Val Arg Lys Lys Glu Glu Tyr Lys Met Ala Leu Tyr Asn Leu Tyr Pro		
1060	1065	1070
Gly Val Phe Glu Thr Val Glu Met Leu Pro Ser Lys Ala Gly Ile Trp		
1075	1080	1085
Arg Val Glu Cys Leu Ile Gly Glu His Leu His Ala Gly Met Ser Thr		
1090	1095	1100
Leu Phe Leu Val Tyr Ser Asn Lys Cys Gln Thr Pro Leu Gly Met Ala		
1105	1110	1115
Ser Gly His Ile Arg Asp Phe Gln Ile Thr Ala Ser Gly Gln Tyr Gly		
1125	1130	1135
Gln Trp Ala Pro Lys Leu Ala Arg Leu His Tyr Ser Gly Ser Ile Asn		
1140	1145	1150
Ala Trp Ser Thr Lys Glu Pro Phe Ser Trp Ile Lys Val Asp Leu Leu		
1155	1160	1165
Ala Pro Met Ile Ile His Gly Ile Lys Thr Gln Gly Ala Arg Gln Lys		
1170	1175	1180
Phe Ser Ser Leu Tyr Ile Ser Gln Phe Ile Ile Met Tyr Ser Leu Asp		
1185	1190	1195
Gly Lys Lys Trp Gln Thr Tyr Arg Gly Asn Ser Thr Gly Thr Leu Met		

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1205	1210	1215
Val Phe Phe Gly Asn Val Asp Ser Ser Gly Ile Lys His Asn Ile Phe		
1220	1225	1230
Asn Pro Pro Ile Ile Ala Arg Tyr Ile Arg Leu His Pro Thr His Tyr		
1235	1240	1245
Ser Ile Arg Ser Thr Leu Arg Met Glu Leu Met Gly Cys Asp Leu Asn		
1250	1255	1260
Ser Cys Ser Met Pro Leu Gly Met Glu Ser Lys Ala Ile Ser Asp Ala		
1265	1270	1275
Gln Ile Thr Ala Ser Ser Tyr Phe Thr Asn Met Phe Ala Thr Trp Ser		
1285	1290	1295
Pro Ser Lys Ala Arg Leu His Leu Gln Gly Arg Ser Asn Ala Trp Arg		
1300	1305	1310
Pro Gln Val Asn Asn Pro Lys Glu Trp Leu Gln Val Asp Phe Gln Lys		
1315	1320	1325
Thr Met Lys Val Thr Gly Val Thr Thr Gln Gly Val Lys Ser Leu Leu		
1330	1335	1340
Thr Ser Met Tyr Val Lys Glu Phe Leu Ile Ser Ser Ser Gln Asp Gly		
1345	1350	1355
His Gln Trp Thr Leu Phe Phe Gln Asn Gly Lys Val Lys Val Phe Gln		
1365	1370	1375
Gly Asn Gln Asp Ser Phe Thr Pro Val Val Asn Ser Leu Asp Pro Pro		
1380	1385	1390
Leu Leu Thr Arg Tyr Leu Arg Ile His Pro Gln Ser Trp Val His Gln		
1395	1400	1405
Ile Ala Leu Arg Met Glu Val Leu Gly Cys Glu Ala Gln Asp Leu Tyr		
1410	1415	1420